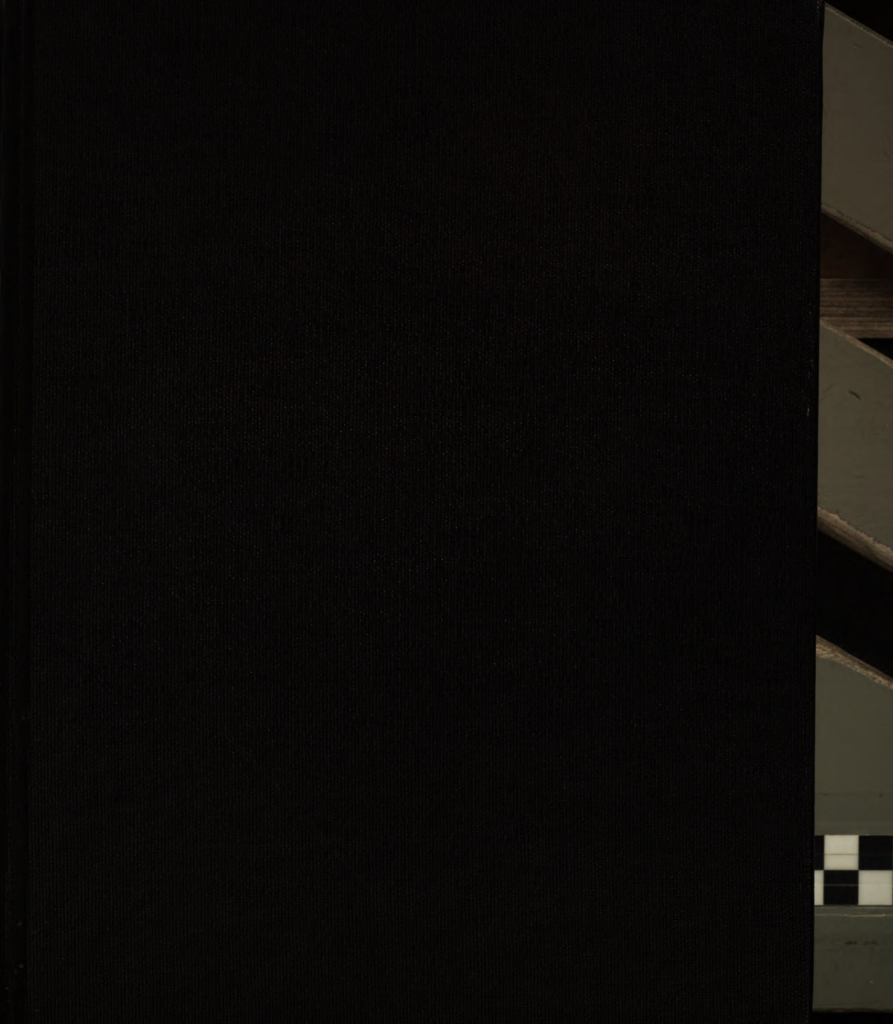






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BIOMECHANICS OF THE RUNNING GAIT
OF RECREATIONAL RUNNERS WHO ARE BLIND

presented by

Tasos Karakostas

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of the requirements for

M.S. degree in P.E.E.S.

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**BIOMECHANICS OF THE RUNNING GAIT
OF RECREATIONAL RUNNERS WHO ARE BLIND**

By

Tasos Karakostas

A THESIS

**Submitted to
Michigan State University
in partial fulfilment of the requirements
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1993

ABSTRACT

BIOMECHANICS OF THE RUNNING GAIT OF RECREATIONAL RUNNERS WHO ARE BLIND

By

Tasos Karakostas

The purpose of this study was to analyze and compare selected kinematic and kinetic variables of the running gait of recreational runners: those who were blind and those who were sighted. The subjects consisted of two individuals whose age at onset of blindness was before five years, three individuals whose age at onset of blindness was after five years, and two individuals who were sighted. Age ranged from 36 to 47 years.

Subjects who were blind ran using a guide cable. Sighted subjects ran under three conditions: naturally, using a guide cable, and blindfolded using the guide cable. Kinetic data were collected on six successful trials that ranged from 2.4 to 3.8 m/s. An AMTI force platform was used to obtain ground reaction forces. High-speed cinematography was used to obtain body motion and position information for five trials. Comparisons of performance were made among the groups for foot strike, mid-stance, and toe-off.

Runners who were blind were less efficient in their running technique than sighted runners. Runners whose age at onset was before five were less efficient than runners whose age at onset was after five. Conclusions could not be drawn for the blindfolded runners.

**To My Mother, Mrs C. Karakosta, my grandfather,
my marathon runner friend who is blind, and to
the memory of my grandmother**

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

Sports, for persons with disabilities¹, can provide numerous beneficial physiological, psychological, and sociological outcomes, such as increased cardiovascular endurance, improved self-esteem, and alertness (Weitzman, 1985, 1986). Individuals who are blind constitute a disability group for whom running is a sport that may provide many beneficial outcomes previously identified (Laughlin, 1975; Stephens, 1973; Weitzman, 1985).

Coaches, physical educators, and recreational personnel who work with individuals who are blind need more information about the characteristics of their movement patterns (Hanna, 1986; Sherrill, Rainbolt, & Ervin, 1984). If information about the movement patterns of individuals who are blind were available, factors that underlie performance could be more clearly understood and more efficient instruction could be provided to maximize individual performance and minimize the likelihood of injury.

Statement of the Problem

There is a lack of information in the literature that describes the recreational running and/or jogging patterns of individuals who are blind and who are classified within the B1 category established by the United States Association for Blind Athletes (USABA). Individuals in the B1 category have the greatest degree of visual

¹ The terminology used in this project to describe persons with disabilities is from the Research and Training Center on Independent Living (1990).

disability (e.g., those who possess some light perception, but no visual acuity, and/or those with 3° or less in visual field) and the worst performance scores in sprint running when compared to the performance of other classifications of athletes who are blind (Arnhold & McGrain, 1985; Gorton & Gavron, 1987; Pope, McGrain, & Arnhold, 1984). The low performance scores of the B1 athletes seem to be the result of poor sprinting technique (Arnhold & McGrain, 1985; Gorton & Gavron, 1987; Pope et al., 1984). One approach to a better understanding of this problem is to study selected kinetic and kinematic characteristics associated with the low performance standards of individuals who are blind and involved in recreational running.

There is also a lack of information about the effect of age at onset of blindness on the running or jogging patterns of recreational runners. Evidence suggests that, when performing motor tasks, individuals who have lost their sight after the age of five may have an advantage over those who have lost their sight before the age of five because the former retain some visual frame of reference (Arnhold & McGrain, 1985; Hardman, Drew, Egan, & Wolf, 1990; Lowenfeld, 1980; Schlaegel, 1953).

Need for the Study

Evidence indicates that many people who are blind want to participate in sport activities (Delaney & Nuttall, 1978). In a survey conducted by Delaney and Nuttall (1978) in Massachusetts, recreational experiences, and particularly participation in sports, were ranked as the most important among the middle priority unmet

needs for the population who were blind. (Transportation services was ranked as the most important among the high priority unmet needs). The importance of sport activities for the blind was expressed by Weitzman (1985), who said that "no blindness rehabilitation program will be completely successful without an appropriate athletic component" (p. 99).

Running is one sport that athletes who are blind may enjoy. In a study about the sport socialization of athletes who were blind, running was the most favorite sporting event (Sherrill, Pope, & Arnhold, 1986). A recreational program based on jogging can be a very appropriate activity for individuals who are blind because it meets physical and social needs as well as financial interests (Webster, 1973). Jogging is practical and inexpensive; it is a lifetime activity; it is independent of weather; and, because it requires little equipment, it is easily transferable to the home and community setting after initial training in a rehabilitation center (Sonka, 1978; Webster, 1973).

Improved mobility and orientation skills also have been reported as beneficial outcomes of running. Sonka (1978) observed that distance running can reinforce skills and concepts necessary for safe and proficient travel for the person with visual disability. It can reinforce the concepts of right, left, or straight ahead, and of clockwise, time, and distance. In addition, distance running can develop a heightened awareness of sensory cues and improve posture and gait.

The improved cardiovascular performance resulting from exercise by individuals who are blind has been documented by several

researchers (Laughlin, 1975; Sonka, 1978; Stamford, 1975; Titlow & Ishee, 1986; Weitzman, 1985). The psychological benefits of exercise, in particular running, such as increased self-confidence and improved self-esteem, for individuals who are blind also have been reported by many researchers (Buell, 1979; DePauw, 1981; Hanna, 1986; Laughlin, 1975; Weitzman, 1986, 1985).

Another reason why running is so popular as a recreational activity, is that the occurrence of injury in running and jogging is less frequent when compared to other recreational activities (Marti, Vader, Minder, & Abelin, 1988).

Runners who have sight experience injuries. Although literature on the incidence of injuries for runners who are blind could not be found by the investigator, it is logical to believe that runners who are blind will also be exposed to the risk of injury.

The literature for sighted individuals indicates that distance running injuries usually are the result of overuse, stress, exertion, and/or accumulated impact loading. Most studies report that the majority of these injuries are associated with training errors, i.e., incorrect technique and/or high weekly mileage (James, Bates, & Osternig, 1978; Lysholm & Wiklander, 1987; Marti et al., 1988).

Long distance runners are more likely to have problems in the lower extremities, in particular, the ankle and the knee; whereas, middle distance runners are more likely to experience low back pain and hip problems (James et al., 1978; Lysholm & Wiklander, 1987; Marti et al., 1988). Hajek and Noble (1982) have reported a number of cases of stress fractures at the neck of the femur in joggers and runners. James et al. (1978) and Clancy (1980), who provide a

description and treatment for the most frequent injuries of runners and joggers, indicated that the running injuries were associated with a number of lower limb conditions combined with ground reaction forces (GRF). James et al. (1978) concluded that examination of the foot and leg mechanics from a practical standpoint is effective in the diagnosis and treatment of these injuries.

Whenever an athlete gets injured, physical involvement in the sport usually is discontinued for a period of time (Clancy, 1980; James et al., 1978). Unfortunately, progress in a sport requires continued participation. One way that continued participation can be achieved is by avoiding injury. Avoidance of injury is partially dependent on the use of correct technique. Thus, using correct running technique minimizes the likelihood of injury and maximizes running efficiency (speed and especially distance).

Many biomechanical research studies have been conducted on sighted athletes in order to investigate the techniques involved in jogging and running gait (Armstrong & Cooksey, 1983; De Vita & Bates, 1988, Hamill, Bates, Knutzen, & Sawhill, 1983; Holden, Cavanagh, Williams, & Bednarski, 1985; Snel, Delleman, Heerkens, & van Ingen Schenau, 1985) . These studies have provided kinetic and kinematic descriptions of running and jogging. However, there is a lack of information in the literature describing the characteristics of the running patterns of recreational runners who are blind.

Biomechanical analysis of the function of the lower extremities of recreational runners who are blind would provide insight into the characteristics of their gait. Recreational personnel and physical

educators should be aware of the running techniques used by individuals who are blind. They also should be aware of the effect of age at onset of blindness, as well as the effects of aids, such as a guide cable, on the running patterns of individuals who are blind. Such knowledge may enable recreational personnel and physical educators to design appropriate programs, have realistic expectations, and provide appropriate instructions. Knowledge of the biomechanical characteristics of the running patterns of recreational athletes who are blind could provide information to educators to help individuals who are blind improve the technical aspects of their running. In this way, the likelihood of continued participation in vigorous physical activity might be enhanced.

In addition, in the case of injury, biomechanical evaluation or knowledge of the mechanical functioning of the lower extremities can assist the physician and the physiotherapist in diagnosis and treatment of the injury, as well as in helping to monitor progress during recovery. Furthermore, the need for kinetic and kinematic knowledge of the movement patterns of individuals who are blind is strengthened even further if one takes into consideration the fact that the majority of sports require running as a warm-up activity. This implies that many athletes who are blind, although involved in other sports (e.g., goal ball and wrestling), are likely to engage in some form of running at some stage during their training session.

Another reason that supports the necessity of this study is the need to develop a protocol for obtaining biomechanical information about recreational athletes who are blind. The protocol introduced

in this study may provide information which can contribute to future research in this area.

Purpose

The primary purpose of this research was to study selected kinematic and kinetic variables in the running patterns of individuals who are blind. More specifically, the purpose was to study the kinematics of their running patterns and to quantify the ground reaction forces exerted on the bodies of B1 recreational runners. The results were compared with sighted recreational runners that were tested on the same variables. A secondary purpose of this study was to investigate the effect of age at onset of blindness on running patterns. In addition, the effect of a guide cable on running technique was studied by testing sighted runners who performed with and without the use of the guide cable. Finally, this researcher intended to introduce a testing protocol that could be used in other studies that seek kinematic and kinetic information on recreational runners who are blind.

Hypotheses

Individuals who are blind have less efficient sprinting and walking patterns than sighted athletes (Arnhold & McGrain, 1985; Clark-Carter, Heyes, & Howarth, 1987; Dawson, 1981; Gorton & Gavron, 1987; Hamill, Knutzen, & Bates, 1985; Knutzen, Hamill, & Bates, 1985; MacGowan, 1985; Pope et al., 1984; Stamford, 1975; Titlow & Ishee, 1986). B1 sprinters, in turn, have more inefficient sprinting and walking patterns than athletes in other less visually impaired classifications. Furthermore, a distinction may need to be

made among athletes within the B1 classification. The literature supports the view that, in general, individuals who have lost their sight after the age of five years have an advantage over those whose onset of blindness occurred earlier than the fifth year of their life. Individuals who lost their sight after the age of five are able to retain some visual frame of reference (Arnhold & McGrain, 1985; Hardman et al., 1990; Lowenfeld, 1980; Schlaegel, 1953). This suggests that individuals who lost their sight after the age of five years may be more efficient in their movement patterns than those who became blind before their fifth birthday.

The following hypotheses were tested in this study:

1. At similar velocities, B1 recreational runners will have a longer contact period with the ground during the support phase of running than recreational runners who are sighted (S).
2. At similar velocities, B1 recreational runners will cover less distance per stride relative to their lower limb length when they run than S runners.
3. S runners will demonstrate more efficient kinematic patterns, during running, than B1 recreational runners.
4. B1 recreational runners who became blind before the age of five years (BB) will demonstrate less efficient kinematic patterns when they run than runners who became blind after the age of five years (BA).
5. At similar velocities, B1 recreational runners, in general, will experience greater ground reaction forces, relative to their body weight, when they run than do S runners.

6. At similar velocities, BB runners will experience greater ground reaction forces, relative to their body weight, when they run than will BA runners.

7. The kinetic and kinematic patterns of sighted recreational runners will be less efficient when they use a guide cable (SC) than when they run without one (S).

8. At similar velocities, the kinetic and kinematic patterns of recreational runners who are sighted will be less efficient when using a guide cable while blindfolded (SB) than when they run with full vision using a guide cable (SC).

Research Design

This project is a descriptive study. Because of the lack of relevant information in the literature, its purpose was to identify and describe selected kinetic and kinematic characteristics of B1 athletes engaged in recreational running and to compare them with those of sighted individuals. In addition, the effect of age at onset of blindness and the effect of the use of a guide cable on the running technique of B1 athletes and sighted athletes was investigated.

Operational Definitions

Adventitiously blind: Blindness that occurred after birth.

Age at onset of blindness, or age at onset: It is the age at which an individual became legally blind or lost sight completely. For this study, the latter is implied by "the age at onset", i.e., the person who likes to run is blind and falls under the B1 classification for blind athletes.

BA: This is a classification used in this study for a recreational runner who is blind and the age at onset was after five years.

BB: This is a classification used in this study for a recreational runner who is blind and the age at onset was before five years.

Blind: For the purpose of this study, blind means no usable vision as it relates to participation in sports, although the ability to perceive light may be present. This definition also includes individuals with visual field 3° or less. Note that field of vision is the angle that subtends the widest diameter a person can see. This definition was adopted from the USABA (1982) classifications for athletes with visual disabilities who would be placed in the Class A or B1 category.

Congenitally blind: Blindness that occurred at birth.

Crossover: The point where the individual moves from the braking portion of the anterior-posterior ground reaction force to the propulsive portion of the anterior-posterior ground reaction force. It is also the point where the individual moves from the medial or lateral portion of the medio-lateral ground reaction force, to the lateral or medial portion of the medio-lateral ground reaction force.

Cycle length: The distance covered from the foot strike of one foot to the next foot strike of the same foot.

Dominant leg: The leg with the shorter stance phase, and it usually is responsible for higher accelerating and propulsive forces.

First stride: The first complete stride that was captured in the field of the cinematographic camera.

Foot strike: The part of the gait cycle at which the foot of the swinging leg comes in contact with the ground. It marks the beginning of the stance phase.

Ground reaction force: Every time a runner's foot contacts the ground, the runner experiences a reaction force from the ground to the foot which is equal and opposite to the force with which the runner's foot contacts the ground. This force is called the ground reaction force (GRF) and is divided into F_z , the force applied in the vertical direction, F_y , the force applied in the anterior-posterior direction, and F_x , the force applied in the medio-lateral direction.

Kinematic variables: Variables that describe the linear and angular position and movement of the individual and his body parts in terms of displacement, velocity, and acceleration.

Kinetic variables: Forces responsible for the movement of the individual.

Mid-stance: The part of the stance phase where the shank of the leg is at 90° with the foot.

Nondominant leg: The leg with the longer stance phase, and it usually is responsible for lower accelerating and propulsive forces.

Recreational runner: A person who likes to jog and/or run for pleasure. A recreational runner does not necessarily have a high level of competitive experience in jogging or running in the same way that a competitive runner would have. A recreational runner does not typically run more than ten miles per week or run regularly more than two or three times a week. The purpose for participating in running is purely recreational, i.e., to pleasantly occupy the time after work is done, not a means for making a living.

S: This is a classification used in this study for a recreational runner who is sighted.

SB: This is a classification used in this study for a recreational runner who is sighted, and who runs with the use of the guide cable, but he is blindfolded.

SC: This is a classification used in this study for a recreational runner who is sighted, and who runs with the use of the guide cable and uses his vision.

Second stride: The second complete stride that was captured in the field of the cinematographic camera.

Stride or step length: The distance covered from the foot strike of one foot to the foot strike of the other foot.

Support, or stance phase: The time period during which one foot of the athlete is supported by the ground. The support phase in running starts at the time the foot of the one leg strikes the ground and ends when the toe of the same leg loses contact with the ground. Note that in a cycle there is a stance phase on the right foot and on the left foot.

Swing (recovery) phase: It is the period of time a foot is off the ground, e.g., from "toe-off" to "foot strike" of the same foot. Note that in a cycle there are two swing phases.

Toe-off: The part of the gait cycle at which the toe of the supporting foot leaves the ground. It marks the end of the stance phase.

Transition: The point where the individual moves from the decelerating portion of the vertical ground reaction force to the accelerating portion of the vertical ground reaction force. It is also

the crossover point for the anterior-posterior and medio-lateral ground reaction forces.

Delimitations and Limitations

This study was delimited as follows:

1. Only one cinematographic camera was used to record the running style of the subjects. Its view was in the sagittal plane, therefore, the analysis was two-dimensional.
2. All the subjects were males. There was an effort to identify at least two female recreational runners who could meet the criteria for participating in the project, but none were found.
3. The subjects were recreational runners who were blind and fell in the USABA B1 classification (USABA, 1982). Athletes that fell within the B1 category were selected because they appear to have the lowest performance scores in running among the USABA classifications.
4. The study was conducted in a laboratory setting. There were no inclines or declines over which the subjects had to run, nor were there any surface hazards such as rocks, roots, loose ground, ruts, or debris.
5. The runway allowed enough distance for the individuals who were blind to achieve their normal running gait pattern.

The limitations that exist in generalizing the results of this study are:

1. The running performances of only six subjects, four blind and two sighted, were analyzed for this study.

2. The subjects were adult recreational runners. Children and youth may exhibit different patterns of movement because of developmental factors and differences in environmental experiences.

3. The data may not be generalized to individuals who have multiple disabilities.

4. The study included only male subjects. Female subjects may experience different ground reaction forces and movement patterns.

5. The runway did not provide enough distance to permit the sighted runners to achieve their normal running gait when running under the S and SC conditions.

CHAPTER II

LITERATURE REVIEW

The purpose of this chapter was to review studies that have examined the kinetic and kinematic characteristics of sprinting and running in sighted individuals as well as in individuals who are blind. The first part of this chapter focuses on the running characteristics of sighted individuals. The second part examines the available literature on the same characteristics in individuals who are blind. The last section contains the hypotheses resulting from the review of literature that became the basis of the current study.

Running of Athletes who are Sighted

Generally, it has been established that human gait has two modes, walking and running (Enoka, 1988). During walking, there always is at least one foot on the floor, single stance, and for a brief period in each cycle, both feet are on the floor, double stance. However, when running the individual experiences an alternating sequence of stance and non-stance, i.e., flight (Mann, Moran, & Dougherty, 1986). During a single cycle in both walking and running, each limb experiences a sequence of support or the stance phase and non-support, or the swing/recovery phase (Enoka, 1988). This review shall be limited to the running mode of gait.

The speed of the runner is determined by the distance covered with each stride taken (stride length), and the number of strides taken in a given time (stride frequency, stride cadence, or stride rate). To increase speed, a runner must either increase both

parameters or increase one parameter without reducing the other a comparable amount (Deshon & Nelson, 1964; Hay, 1985; Saito, Kobayashi, Miyashita, & Hoshikawa, 1974;). However, the preferable way for an athlete to increase speed is by increasing the stride length because it requires less energy expenditure (Enoka, 1988). The stride length of the runner is the sum of:

1. **The Take-off Distance:** The horizontal distance that the runner's center of gravity is in front of the toe of the driving leg at take-off (at the instant the driving leg leaves the floor). This distance depends on the length of the runner's leg and the range of movement he or she has at the hip. The length of the runner's leg is related to the physical characteristics of the individual. The range of movement at the hip involves the extent to which the runner extends the leg before take-off and the angle this leg makes with the horizontal at that time, i.e., the position of the individual's body.

2. **The Flight Distance:** During the airborne phase, the runner's body is a projectile. Therefore, the horizontal component of flight distance depends on the velocity, angle of take-off, height of the center of gravity at take-off, height of the center of gravity at landing, and the air resistance experienced in flight. The velocity of take-off is the most important parameter. Velocity is determined by the ground reaction forces (GRF) experienced by the athlete which in turn are determined by the muscular ability of the individual to contract the leg muscles in order to push against the running surface. The GRF are the result of muscular contractions causing extension at the hip, and the knee, and plantar flexion at the ankle joints to

produce the force that the runner exerts against the ground.

3. **The Landing Distance:** The landing distance is the horizontal distance that the toe of the runner's leading foot is forward of his or her center of gravity at the instant he/she lands. The runner, however, does not try to increase that distance. The forward motion of the foot as it hits the ground generates a "braking" reaction that reduces the runner's forward speed (Hay, 1985). The average stride length of male sprinters during a 200 m race was found to be equal to 1.14 times the athlete's height or 2.11 times the athlete's leg length (Hoffman, 1965).

Stride frequency is determined by how long it takes a runner to complete one stride. The longer it takes, the less strides are performed in a given time period. The time it takes a runner to complete one stride depends on:

1. The time that the athlete is in contact with the ground. This contact time is determined by the speed of muscular contraction of the supporting leg to drive the body forward and then forward and upward into the next airborne phase.

2. The time the athlete spends in flight. Time in flight is dependent upon the velocity, take-off angle, height of the center of gravity at take-off, and the air resistance encountered during flight.

An efficient running pattern is achieved through the coordination of the lower extremities, trunk (including the neck and head), and arms. For the purpose of this review, the function of each of these components was reported separately.

The action of the legs is sequential and cyclic. Each foot, in turn, lands on the ground; the leg supports the body as it passes over the foot; and the foot then leaves the ground to move forward again, ready for the next landing. It is well documented that as speed of gait increases, cycle time (foot strike to foot strike of the same foot) decreases (Brandel, 1973; Hay, 1985; Mann & Hagy 1980; Mann et al., 1986). For example, Mann et al. (1986) reported cycle time values of 1000, 800, 700, 540 ms for walking, jogging, running, and sprinting, respectively; resulting in average speeds of 1.32, 3.31, 4.77, and 10.8 m/s. This cyclic leg pattern is typically divided into three phases: (a) the initial stance phase, (b) the driving phase, and (c) the recovery phase.

Kinetics of Running

Initial Stance Phase

The initial stance phase begins when the foot lands on the floor and ends when the athlete's center of gravity passes forward of it. The function of this phase is to arrest the runner's downward motion that is imparted by gravity during the time he/she is airborne and to allow him/her to move into position to drive the body forward and upward with minimum loss of momentum during the driving phase.

Foot strike. Foot strike (FS), occurs when some part of the foot contacts the ground, not necessarily the heel first. Cavanagh (1981), Cavanagh and Lafortune (1980), Munro, Miller, and Fuglevand (1987) have classified runners as rear-foot and mid-foot strikers. Joggers and runners who initially land on the posterior lateral part of their

foot are termed rear-foot strikers while those who land at approximately mid-shoe are termed mid-foot strikers. However, sprinters tend to have a forefoot strike (Brandel, 1973; Nett, 1964) and subsequently lower their heel to the track (Hay, 1985; Payne, 1978, 1983). Cavanagh (1981) reported that the average foot angle (the angle between the foot orientation and the direction of movement) was 10.4° for rear-foot runners and 5.3° for mid-foot runners. However, Holden et al. (1985) reported average foot angles (FA) of 4.7° , 5.1° , and 9.0° for speed ranges of 2.34 to 3.61, 3.61 to 5.13, and 5.14 to 8.61 m/s, respectively. They also reported that the foot angles of the dominant leg (dominant leg in this study was the subjects' preferred leg for kicking), were larger when compared to the foot angles of the nondominant leg. The results of both studies referred to abduction angles (the foot was in an toed-out position relative to the direction of movement).

Downward deceleration. After foot strike, runners need to reduce their downward motion to zero. Thus, when the foot contacts the ground, flexion of the hip and knee joints, and dorsi-flexion of the ankle joints are increased to cushion the shock of impact.

The shock of impact, or the maximum deceleration, has been investigated by a number of researchers. Frederick, Hagy, and Mann (1981) have termed the maximum deceleration as the vertical impact force peak. It occurred 20 to 30 ms after FS. Munro et al. (1987) reported that the maximum deceleration occurred between 6 and 17 percent of total stance time, and its magnitude raised from 1.6 times body weight (BW) at 3.0 m/s to 2.3 times BW at 5.0 m/s. Cavanagh

and Lafortune (1980) showed that the maximum deceleration is affected by foot posture at landing. They used center of pressure measurements for running at 4.5 m/s and found that mid-foot strikers had no maximum deceleration peak. This finding was also supported by Payne (1978, 1983) who stated that sprinters without heel contact have no maximum deceleration peak and have smoother patterns in the horizontal (F_y) forces. They also found that rear-foot strikers demonstrated mean values for maximum deceleration peak of 2.2 times BW which occurred at 23 ms after FS. For the same speed, Clarke, Frederick, and Cooper (1983) reported average maximum deceleration peak values of 2.3 times BW that occurred at 24.9 ms after FS. Hamill et al. (1983) gave maximum deceleration peak values of 3.2 times BW, 3.0 times BW, and 4 times BW occurring at 9.2, 8.7, 8.3, and 8.5 percent of stance phase, respectively.

Nigg, Denoth, and Neukomm (1987) referred to the maximum deceleration peak as a passive force which was absorbed less well by the body since its high frequency is around 20 ms while the muscular system has a latent period of 30 ms or more. This means that the maximum deceleration peak occurs faster than the body can recruit muscles, the most efficient shock absorbers, to absorb the maximum deceleration peak. Consequently, they noted that ineffective attenuation could result in microtrauma to soft tissue and bone.

Delaying the maximum deceleration peak can be translated as minimizing the rate of loading (the product of time versus maximum deceleration peak). Munro et al. (1987) found the loading rate to increase with the running speed from 77.2 BW/s at 3.0 m/s to 113.0

BW/s at 5.0 m/s (the loading rate being for the vertical force to rise from 50 N -Newton- to body weight plus 50 N).

Braking. Whether or not an athlete's forward momentum is reduced during the stance phase depends on the nature of the anterior-posterior forces exerted by the foot on the ground or, more precisely, on the equal and opposite GRF exerted on the athlete's foot during stance time. The magnitude and direction of the GRF's are governed by the velocity of the foot relative to the ground at that instant of contact. When an athlete is airborne prior to FS, the center of gravity is moving forward with a horizontal velocity determined at the moment the ground was left. The leg and every other part of the body have a velocity lesser or greater than that of the center of gravity depending on each respective body part's direction and relative velocity of movement. Therefore, the only way in which an athlete can ensure that his/her foot is not moving forward relative to the ground at FS, is to have it moving backward relative to the center of gravity with a horizontal velocity at least equal to that at which the center of gravity is moving forward (Hay, 1985). In this manner there would be no retarding/braking horizontal forces evoked at FS. Deshon and Nelson (1964) concluded that efficient running is characterized by placement of the foot as closely as possible beneath the center of gravity of the runner at FS. However, Payne, Slater, and Telford (1968) suggested that even when the foot was placed below or almost below the center of gravity, its backward velocity relative to the velocity of the center of gravity was still insufficient to completely eliminate all retarding effects.

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Cavanagh (1981) and Cavanagh and LaFortune (1980) found in their studies that the retarding force or braking force was .43 times BW for rear foot runners and occurred at approximately 46 ms after FS. Their mid-foot strikers exhibited a braking pattern of two peaks. The first peak was .45 times BW occurring at 11 ms after FS. Then the loading fell to zero or below within 25 ms of contact. The second peak occurred at 38 ms and it was of equal magnitude. This double peak pattern was explained by examining the center of pressure (COP) relative to the foot of the runners. As it was noted before, the center of pressure of the mid-foot strikers migrated posteriorly, and this posterior movement coincided with the drop of the braking component of GRF. However, Hamill et al. (1983) and Payne (1978, 1983) presented evidence which showed that the braking pattern of rear-foot strikers was characterized by two peaks; whereas, that of mid-foot strikers was a single peak. Hamill et al. (1983) reported the maximum braking force to occur at 23, 23.45, 22.36, 21.48 percent of the stance phase for speeds of 7, 6, 5, and 4 m/s, respectively.

Another study reported a variable braking pattern across runners (Munro et al., 1987). This variable braking pattern made the association of FS classification with specific braking patterns difficult. The association of the braking pattern with the foot-strike classification was left as a suggestion for future research. Some of their subjects had a braking pattern which peaked at 25 percent of the stance phase, while other subjects had a braking pattern of two peaks occurring at 17 and 24 percent of the stance phase. Still other

subjects had multiple braking peaks. These investigators also found braking force to increase from 0.15 BW at 3 m/s to 0.25 BW at 5 m/s.

Maximum unloading and transition. After the initial stance phase, the runner needs to make a transition to the driving phase. During this transition, the maximum deceleration peak is followed by a decrease in force to a relative minimum, or maximum unloading. This is associated with hip and knee flexion as well as dorsi-flexion of the foot to absorb the impact. The value of the relative minimum vertical force, indicates the runner's ability to absorb the load of the impact. The braking force is reduced to zero during this transition, and at this instant the center of gravity is directly over the base of support. The greater the speed of the runner, the faster this decrease occurs.

Hamill et al. (1983) reported the relative minimum, or maximum unloading force in the vertical direction to be 1.78, 1.70, 1.40, 1.20, BW for speeds of 7, 6, 5, 4 m/s occurring at 17.61, 17.02, 16.31, 15.65 percent of the stance phase, respectively, for ten skilled distance runners. De Vita and Bates (1988) reported the relative minimum force to be between 2.1 and 1.4 BW for the first five to ten trials of six skilled male runners 21 to 31 years of age who ran between 4.0 and 4.5 m/s. The maximum unloading force occurred between 14.9 and 11.5 percent of the stance phase. Munro et.al. (1987) reported the relative minimum force to increase from 1.28 BW for a speed of 3 m/s to 1.75 BW for a speed of 5 m/s.

The time from FS to the transition from braking to acceleration is the time required for the center of gravity to pass over the base of

support. Munro et al. (1987) reported this transition to occur consistently at 48 percent of the stance phase. Hamill et al. (1983) reported this time to occur at 42.5, 46.8, 49, 49.9 percent of the stance phase for speeds of 7, 6, 5, 4 m/s, respectively. Cavanagh and Lafortune (1980) also reported the transition to occur at 48 percent of the stance phase for both rear-foot and mid-foot strikers who ran at 4.5 m/s.

Driving Phase

During the driving phase, the runner's goal is to drive or thrust the support foot downward and backward against the ground. In this way, the body will be accelerated upward and propelled forward.

Upward acceleration. Cavanagh (1981) and Cavanagh and Lafortune (1980) reported the accelerating force or the second peak of the vertical force curve to be 2.8 times BW and to occur 83 ms after FS for rear-foot strikers. For mid-foot strikers, this force was 2.7 times BW for speeds of 7, 6, 5, 4 m/s and occurred at 45.9, 44.5, 42.5, 43.8 percent of the stance phase, respectively. Munro et al. (1987), who called this accelerating force "thrust", reported that it occurred from 35 to 50 percent of the total stance phase, and its magnitude increased from 2.5 times BW at 3 m/s to 2.8 times BW at 5.0 m/s. Roy (1981) reported acceleration forces ranging from 2.8 to 3.0 times BW for twenty subjects running at 3.4, 3.8, 4.8, and 5.4 m/s.

Forward propulsion. The F_y force with which the body is propelled forward is determined by the foot strike pattern and running speed of

the individual. For propelling force, Cavanagh (1981) and Cavanagh and Lafortune (1980), reported peak values of 0.5 times BW at 139 ms and 133 ms for rear-foot and mid-foot strikers, respectively. Hamill et al. (1983) reported peak propelling force values ranging from 0.11 times BW at 4 m/s to 0.19 times BW at 7 m/s occurring from 73 percent to 72 percent of the stance phase, respectively. Munro et al. (1987) reported the propulsive impulse increased from 0.14 times BW at 3 m/s to 0.25 times BW at 5 m/s.

Medio-lateral Force

During the stance phase, the runner experiences another component of the GRF. This is the mediolateral or F_x component. Throughout the literature there was general agreement that this component of the GRF was characterized by extreme inter- and intra-subject variability (Bates, Osternig, Sawhill, & Hamill, 1983; Cavanagh, 1981; Cavanagh & Lafortune 1980; Hamill et al., 1983; Munro et al., 1987). The medio-lateral force component values in these studies for individuals running at comparable speeds were found to be relatively small when compared with the anterior-posterior (F_y) and vertical (F_z) force component values. Cavanagh and Lafortune (1980) reported double medial and double lateral peaks with peak to peak amplitudes at 0.12 times BW for rear-foot strikers and 0.35 times BW peak-to-peak amplitudes for mid-foot strikers. The diagrams presented in the study of Hamill et al. (1983) showed both the medial and the lateral forces to be 0.15 times BW. Bates et al. (1983) have shown averages to range from approximately 0.20

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times BW medial to 0.35 times BW lateral. Munro et al. (1987) found no relationship between maximum medial or lateral GRF and running speed between 3.0 and 5.0 m/s. Munro et al. (1987) reported averages ranging from 0.04 to 0.25 times BW for the medial GRF and from 0.06 to 0.31 times BW for lateral GRF. They found peak-to-peak amplitudes for individual subjects to average between 0.20 and 0.50 times BW with the mean for the whole group being 0.29 times BW.

General Remarks

During the stance phase, the vertical component of the GRF has a double peak configuration for the rear-foot strikers and a single peak for the mid-foot strikers. The peak vertical component was proportional to running speed (Cavanagh & Lafortune, 1980; De Vita & Bates, 1988; Hamill et al., 1983; Munro et al., 1987) and inversely proportional to the duration of stance time.

The anterior-posterior component of the GRF during running has been characterized predominantly as biphasic with the first part constituting a braking phase and the second part constituting a propelling phase. For a constant velocity to be maintained, the propelling force must compensate for the braking force. However, when an individual runs, the propelling force appears to be greater than the braking force. This was because air resistance caused a speed decrement of about one percent which must be overcome by the propulsion phase (Hamill et al., 1983; Munro et al., 1987;).

The COP patterns of runners have been used to explain GRF patterns (Cavanagh & Lafortune, 1980; Munro et al., 1987). For rear-

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foot strikers, the COP continues medially following FS. Cavanagh and Lafortune (1980) reported that this occurred within 15 ms of contact. The COP then moved quickly anteriorly until toe-off. Cavanagh and Lafortune reported that before toe-off, the COP was centered under the front part of the shoe approximately two thirds of the entire 200 ms contact phase. For mid-foot strikers, Cavanagh and Lafortune (1980) reported that after initial contact, the COP moved posteriorly. At the same time, the rear part of the shoe contacted the ground. The COP then moved quickly to a position under the forepart of the shoe, and it remained there for the majority of the stance phase. The relative time that the COP traveled was shorter for midfoot strikers than for rear-foot strikers. The relative time that the COP traveled is different from the time of the stance phase. A synopsis of the selected studies on the pertinent variables can be seen in Table 2.1.

Kinematics of Running

As previously indicated, a runner needs to absorb the shock of impact with the ground by flexing at the hip, and knee, and dorsi-flexing at the ankle joints. During the driving part of the stance phase, the runner needs to extend the same joints to project his/her body forward to the next stride.

Table 2.1

A synopsis of kinetic information on the ground reaction forces for running.

Authors	Maximum Downward Deceleration	Braking Force	Maximum Unloading	Transition Time	Upward Acceleration Force	Forward Propelling Force	Medial(+) Lateral(-) Force
Bates et al. (1983)							(+0.20)- (-0.35) BW
Cavanagh & LaFortune (1980)	2.2 BW 23 ms	0.43 BW 46 ms 11 & 38 ms		48%	2.8 BW 83 ms 2.7 BW 45.9-42.5%	0.5 BW 139 & 133 ms	0.12 BW 0.35 BW
Clarke et. al. (1983)	2.3 BW 25 ms						
De Vita & Bates (1988)			1.4-2.1 BW 11.5-14.9%				
Frederick et al. (1981)	20-30 ms						

Table 2.1 continued

Authors	Downward Deceleration	Braking Force	Maximum Unloading	Transition Time	Acceleration Force	Propelling Force	Medial(+) Lateral(-) Force
Hamill et al. (1983)							(+0.15)- (-0.15) BW
Munro et al. (1987)	1.6-2.3 BW 6.0-17.0%*	0.15-0.25 BW 25% or 17 & 24%	1.28-1.75 BW	48%	2.5-2.8 BW 35-50%	0.14-0.25 BW	(+0.04)- (+0.25) BW (-0.06)- (-0.31) BW averages: (+ or -) 0.2- 0.5 BW
Roy (1982)					2.8-3.0 BW		

* Percent of stance phase at which each event occurred.

Stance Phase

The stance phase starts with the foot strike and ends with the toe-off. The function of the lower limb joints is different during each part of the stance phase.

Hip joint. There is general agreement that the stance phase is inversely proportional to speed (Adelaar, 1986; Enoka, 1988; Mann & Hagy 1980; Mann et al., 1986). Mann and Hagy (1980) and Mann et al. (1986) reported that the stance phase in walking was 62 percent, in jogging 32.5 percent, in running 29.5percent, and in sprinting 22-26 percent of the total cycle time.

It has been reported that as the speed of movement increased, the range of motion of the joints of the lower extremity also increased (Mann & Hagy, 1980; Mann et al.,1986). In particular, the hip demonstrated the greatest increase in range of motion among all the joints (Brandell, 1973; Enoka, 1988; Mann & Hagy, 1980; Mann et al., 1986). Therefore, the importance of hip flexibility in runners becomes apparent. Wiklander, Lysholm, and Lysholm (1987) reported that the less flexible the hip, the greater the number of "give away" movements, rotations, took place in the pelvis. These pelvic movements resulted in exertion injuries around the hip and in the lower back. Mann et al. (1986) reported that during the first part of the stance phase, in which the shock impact was absorbed by the hip, the hip was flexed approximately 40° to 50° when jogging at 3.31 m/s, running at 4.77 m/s, and sprinting at 10.8 m/s. Brandell (1973) reported hip flexion of approximately 20° at the initial part of the stance phase for running. During the later accelerating/propulsive part of the stance phase, Mann and Hagy (1980) and Mann et al. (1986) reported extension of the hip joint to be from

about 50° to 15° flexion for jogging and sprinting; whereas, for running, it extended from 50° flexion to 5° hyperextension. Brandell (1973) reported a hip extension angle of approximately 30° for runners.

The ranges of hip flexion-extension during stance phase in running, as reported by different studies, can be seen in Table 2.2.

Table 2.2
Flexion-extension at the hip joint while running.

Authors	Flexion during Deceleration	Extension during Acceleration
Brandell (1973)	20° initially	30°
Mann & Hagy (1980)		50° - 15°
Mann et al. (1986)	40° - 50°	50° - 15°

Knee joint. Increased ranges of flexion and extension at the knee joint occur as the speed of gait increases. Mann and Hagy (1980) reported for running that after FS there was a knee flexion of 35° prior to extension. Knee flexion helped to absorb the impact of the body with the ground. However, during sprinting, the knee performed a continuous progressive extension of about 20°, and it was suggested that most of the absorption of the initial GRF is carried out by the dorsi-flexion at the ankle joint. The degree of flexion of the knee during running and sprinting is approximately 145°. Mann et al. (1986), reported that during the stance phase in jogging and running, the knee flexed 20° and extended

20°; whereas, in sprinting there also was a progressive extension of 20°. They also noted that throughout the stance phase, the knee never fully extended, but it remained at about 30° to 40° flexion. This range of flexion agreed with the range reported by Enoka (1988). The magnitude of flexion was found to increase from approximately 110° for jogging to about 130° for running and sprinting. Brandell (1973) reported similar values for knee flexion during the stance phase for running. Bates, Osternig, Mason, and James (1977) presented a knee angle of approximately 163° for different shoe conditions occurring at FS of a 3.35 to 4.47 m/s pace. From FS knee flexion increased, and at approximately 40% of the stance, maximum knee flexion of 38° had occurred (125° knee angle). This maximum knee flexion was followed by knee extension to toe-off. The knee angle at toe-off was 173°, i.e., at toe-off the knee was still flexed 7°. Smart and Robertson (1985) reported knee flexion of 32 to 34.4°, knee adduction of 10° to 13° and internal rotation of 13° to 15° for a running pace of 4 m/s. The ranges of knee flexion during running reported in the literature can be seen in Table 2.3.

Ankle joint. The motion at the ankle joint varies according to the activity (Mann & Hagy, 1980). At FS, during running, dorsi-flexion occurred through the mid-stance phase followed by plantar flexion. Mann et al. (1986) observed that the degree of dorsi-flexion at FS was inversely proportional to the speed of gait. They reported values of 18° for jogging, and 12° for running. During sprinting, they reported 8° of plantar flexion at FS. After plantar flexion at FS, dorsi-flexion occurred was reported to have maximum values of 28° for jogging, 22° for running, and 15° for sprinting. Obviously, although dorsi-flexion

Table 2.3
Values (in degrees) for knee flexion during the stance phase of running.

Table 2.3
Values (in degrees) for knee flexion during the stance phase of running.

Author	Flexion at Foot Strike	Flexion during Downward Deceleration	Flexion at Toe-off	Range of Flexion during Stance Phase	Degrees of Knee Angle
Bates et al. (1977)	17°	38°	7°	31°	163°-140°-173°
Brandell (1973)		20°	20°		
Enoka (1988)				20°-40°	
Mann & Hagy (1980)		35°			145°
Mann et al. (1986)		20°	20°	30°-40°	
Smart & Robertson (1985)				32°-34°	

occurred at FS for jogging and running, sprinters exhibited an initial plantar flexion at FS which indicated a forefoot strike. Bates et al. (1977) reported that dorsi-flexion ranged from 24° at FS to 43° at mid-stance where the maximum dorsi-flexion occurred.

The same authors reported inversion values at FS to be between 8.8° and 10.4° for different shoe conditions. Starting at approximately 39 percent of the stance phase, eversion occurred until 51 percent of the stance phase. Eversion ranged from 7° at 39 percent of stance phase to 6° at 51 percent stance phase. Eversion was followed by inversion at toe-off and ranged from 20° to 23° . Smart and Robertson (1985) reported pronation values for their runners to be: dorsi-flexion 18.8° ; eversion 24.9° ; internal rotation 14.3° . Soutas-Little, Beavis, Verstraete and Marcus (1987) reported pronation and supination data for athletes running at 3.57 m/s. The pronation period was approximately 100 ms for one of the rear-foot strikers. That runner demonstrated plantar/dorsi-flexion of 21° , inversion/eversion of 15.5° and medial/lateral rotation of 16.5° . For a subject who was a mid-foot striker, the pronation period started 15 to 25 ms after FS and ended between 120 and 140 ms. Supination then followed. This runner had 14.5° inversion-eversion, 31° plantar/dorsi-flexion and 14.5° medial/lateral rotation. The pronation/supination values for the ankle during running are represented in Table 2.4.

Recovery Phase

The stance phase is followed by the recovery phase. During the recovery phase the runner's body travels through the air. The athlete combines the actions of the lower body, the trunk, and the arms while

Table 2.4
Values for ankle pronation/supination during the stance phase of running.

Authors	Dorsi-Flexion at Foot Strike	Maximum Dorsi- Flexion	Plantar/Dorsi Flexion Range	Inversion(-) Eversion(+)	Medial/Lateral Rotation	Internal Rotation
Bates et al. (1977)	24.0°	43.0°		(-8.8°)-(10.4°) 39%* (+7.0°)-(+6.0°) 51% (-20.0°)-(23.0°)		
Mann (1986)	18.0°-12.0°	28.0°-22.0°				
Smart & Robertson (1985)	18.8°			+24.9.0°		14.3°
Soutas -Little et al. (1987)			21.0° 31.0°	15.5° range 14.5° range	16.5° 14.5°	

* Percent of stance phase at which each event occurred.

he/she travels like a projectile in preparation for the subsequent FS of the opposite leg.

Lower body. During the recovery phase, the runner's foot is off the ground and brought forward from behind his or her body to prepare for the next FS. After toe-off, the thigh of the same leg begins its forward rotation about an axis through the hip joint formed by the frontal and transverse planes.

Leg movement after toe-off has been referred to as the follow through (Mann et al., 1986). The follow through begins after toe-off and ends with maximum extension of the hip, which occurs less than 50 ms after toe-off when jogging at 3.31 m/s, running at 4.77 m/s, and sprinting at 10.8 m/s. During the recovery phase, the hip reaches its greatest extension of the whole gait cycle. From greatest extension, the forward rotation of the thigh begins. Forward rotation of the thigh ends with maximum hip flexion, and occurs about two-thirds of the way through the recovery phase, coincident with the toe-off of the contralateral foot (Chengzhi & Zongcheng, 1987).

The degree of hip joint flexion increases as the speed of gait increases (Adelaar, 1986; Brandell, 1973; Mann & Hagy, 1980; Mann et al., 1986). In these studies, sprinters demonstrated 10° to 15° more hip flexion than runners, and runners had approximately 20° more hip flexion than walkers. Sinning and Forsyth (1970) found more acute angulation between the trunk and the thigh as running velocity increased. There was also flexion at the knee as the foot was being lifted. Representative maximum hip flexion angles during the recovery are reported in Table 2.5.

Knee flexion during recovery is proportionately related to running velocity. During recovery in sprint running, the foot gets close to the buttocks (Deshon & Nelson, 1964). This knee flexion reduces the moment of inertia of the whole limb about the hip joint so that it can be rotated more quickly. During the later part of the swing/recovery phase, the shank swings forward about the knee while it descends in preparation for the next FS. This event ends with FS and occurs during the last one-third of the recovery phase. The knee begins to flex again before FS.

Sinning and Forsyth (1970) found more acute angulation between the trunk and the thigh as running velocity increased. Mann et al. (1986) reported that maximum hip-flexion was approximately 40° for jogging, 60° for running and 80° for sprinting. The magnitudes of hip-flexion for sprinters, approximately 75°, were comparable to those reported by Chengzhi and Zongcheng (1987). Mann et al. (1986) reported maximum knee flexion values during the recovery phase to increase from about 110° for jogging to about 130° for running and sprinting. Again, these values were comparable to the study of Chengzhi and Zongcheng (1987) who presented a temporal and kinematic analysis of the swing leg of elite sprinters. Chengzhi and Zongcheng (1987) also reported that the period of hip flexion was two times longer than that of hip extension during the recovery phase; whereas, the periods of knee flexion and extension were almost equal.

The ankle reaches its maximum plantar flexion during the recovery phase just after toe-off. This was true for all running speeds (Mann et al., 1986). Maximum plantar flexion was reported to be 45° for jogging and running, and 35° for sprinting. Following plantar flexion, dorsi-flexion begins. However, for sprinting, although dorsi-flexion occurs

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during the forward swing of the recovery leg (as in jogging and running), plantar flexion begins and reaches a maximum just before FS, when dorsi-flexion begins again. The angles of hip, knee, ankle flexion during the recovery phase of running are represented in Table 2.5.

Table 2.5

Values for hip, knee, and ankle flexion during the recovery phase of running.

Authors	Maximum Hip Flexion	Maximum Knee Flexion	Maximum Plantar Flexion
Chengzhi & Zongcheng (1987)	75°	135°	
Mann et al. (1986)	40°-60°	110°-130°	45°

Role of the arms. Throughout the whole running gait cycle, there is arm-leg opposition and some hip rotation. For example, when the left knee is brought forward and upward during the recovery phase of the left leg cycle, the hips are rotated in a clockwise direction. The limit of this rotation is reached when the knee reaches its highest point in front of the body. Then, as the left foot is lowered toward the ground and the right leg begins its forward and upward movement, the hips begin to rotate in a counterclockwise direction. The limit of this rotation is reached as the right knee reaches its highest point in front of the body. At this point, the cycle is complete. However, these rotary actions of the hips result in contrary reactions in the athlete's upper body. As the

left knee is swung forward and upward, the right arm is swung forward and upward, and the left arm is swung backward and upward to balance the angular momentum caused by the leg's movement.

Hinrichs, Cavanagh, and Williams (1983), who studied the contributions of the upper extremity to angular momentum in normal distance running, reported that although the body possesses a relatively large amount of angular momentum about the transverse or X axis and anterior/posterior or Y axis, the arms have a small amount of angular momentum about these axes. The arms, therefore, could not balance the rotation of the body about these axes. They noted that the arms tended to cancel out each other's angular momentum contribution about these axes. However, the authors reported that the arms have a substantial effect on the total body angular momentum about the vertical or Z axis. The angular momentum of the body was occurring as a result of the movement of the legs, and the arms appeared to have a comparable angular momentum, but in the opposite direction. This resulted in a small total body angular momentum about the Z-axis. That meant that for the majority of the subjects, the arms counteracted approximately 80 percent of the body's angular momentum for the majority of the subjects.

The shoulders also might be rotated to balance the hip action. However, during sprint running, such shoulder action is not desirable (Deshon & Nelson, 1964). The arms are flexed at the elbow to about a right angle and the elbow swings backward and forward, and slightly inward.

Role of the trunk. The vertical and horizontal components of the GRF accelerates the runner upward and forward, and if they do not act

through the body's center of gravity, they angularly accelerate the runner. The inclination of the trunk, therefore, is important since it largely determines the position of the runner's center of gravity and thus, too, the lengths of the moment arms between the foot on the ground and the center of gravity. Consequently, by adjusting the inclination of the trunk, the runner can modify the moments involved about the center of gravity, as well as the ankle, knee, and hip joints (Hay, 1985).

To prevent the backward rotating effect of the horizontal component of the GRF, the runner must lean forward to keep the moment arm of the horizontal reaction small. To prevent the forward rotating effect of the vertical component of the GRF, the runner needs to keep the trunk erect. When running at a constant speed, the horizontal component of the GRF is reduced to the point where the overall accelerating effect of the GRF is just enough to balance the retarding effect of air resistance (Hamill et al., 1983). However, there is still the need to counteract the small backward rotating tendencies of air resistance and the horizontal reaction so that the athlete's body will not rotate into a position from which horizontal force cannot be applied in order to maintain constant speed. Consequently, a slight forward lean of the trunk is necessary.

Slocum and James (1968) suggested that the trunk should be erect in preparation for toe-off. However, Atwater (1982) found the trunk leaned forward at an average magnitude of 9° from the vertical at take off. Armstrong and Cooksay (1983) found a mean trunk lean of 8° at toe-off. As was inferred from Brandel's (1973) kinematic graphs of running, at toe-off the trunk demonstrated a forward lean of approximately 11° to 9° , and 11° at FS. It was noticed that the greatest degree of forward

inclination of the trunk, approximately 14° , occurred when the heel was lifted off the ground.

Running of Individuals who are Blind

The three studies found describing the running patterns of athletes who are blind provided only a kinematic description of sprint running. As it is the case for sighted athletes, there was a very high correlation between the stride length and the running velocity of athletes who are blind (Arnhold & McGrain, 1985; Pope et al., 1984). In addition, B1 athletes performed the sprint run using a shorter stride length when compared to B2 and B3 athletes (Arnhold & McGrain, 1985). This was attributed to less range of motion in the hips. Indicators for the shorter stride length of the B1 sprinters were longer stance phase time and shorter airborne phase time (Arnhold & McGrain, 1985). However, Gorton and Gavron (1987) reported results that stride time, stance time, and flight time are similar for B1 and B3 elite blind athletes, but that their stance time was greater than that of able-bodied sprinters, 51.17 percent for B1, 50.62 percent of the total cycle time for B3, and 49 percent for sighted individuals.

For all runners, the hip range of motion is very highly correlated with the running velocity (Arnhold & McGrain, 1985; Pope et al., 1984). B1 athletes, in particular, ran slower because they used less range of motion at the hip than B2 and B3 sprinters (Arnhold & McGrain, 1985; Gorton & Gavron, 1987). During the stance phase, there was a continuing decrease in hip flexion starting from foot strike until toe off for both B1 and B3 athletes. The hip reached maximum flexion at the highest point of knee lift. The hip flexion, during the stance phase (at FS 35.42° for

B3, 30.65° for B1 athletes) and recovery phase (62.31° for B1, 58.83° for B3 athletes), was comparable to the results reported earlier for sighted athletes. Deshon and Nelson (1964) reported hip flexion angles for sighted runners of 63.59° during the swing phase. Slocum and James (1968) reported hip flexion at FS to be between 30° and 40°.

Velocity in sprint running was also found to be related to the upper extremity joint range of motion (Arnhold & McGrain, 1985; Pope et al., 1984). The arm-leg opposition increased forward linear momentum and counteracted the generated angular momentum of the recovery leg. Pope et al. (1984) suggested that because runners who are blind often use assistive devices which restrict the shoulder range of motion, such as rails or guide wires, it is very important for them to increase range of motion at the shoulder joints during running in order to counteract the angular momentum of the hips. An increase in joint range of motion of the upper body can be accomplished by reducing the amount of contact with the assistive device. Arnhold and McGrain (1985) noted that because B1 runners used less range of motion above the hip joint, they ran much slower. The fact that B1 athletes run at a lower velocity, leads to the conclusion that B1 athletes appear to have the most inefficient pattern of sprinting when compared to athletes in the other classifications for the blind. This conclusion is also supported by Winnick and Short (1982).

The head-neck minimum angle to the horizontal and the running velocity of individuals who were blind are negatively correlated (Arnhold & McGrain, 1985; Pope et al., 1984). In the study of Pope et al. (1984) it was determined that this was mainly a characteristic of Class A (B1) runners. This meant that when B1 runners sprinted, they did not lean

forward to get the center of gravity in front of the base of support. In particular, Class A (B1) runners appeared to have a backward lean of the head. However, Gorton and Gavron (1987), in their descriptive study of the running pattern of B1 and B3 elite blind athletes, presented results that disagreed with the two previous studies. This disagreement may be due to the subject populations used in each study (students were used in the first two studies, while elite athletes were used in Gorton's and Gavron's study). The researchers found that there was a similar pattern of head inclination between the B1 and B3 athletes. Some of the runners had an excessive forward lean, while others tended to hold their heads in the same position throughout the entire stride. They speculated that the head inclination might be related to the cause of blindness, i.e., those who tended to tilt their head downward were adventitiously blind. However, the investigators did not report the age of onset for the disability.

Gorton and Gavron (1987) also reported that at foot strike the trunk had a backward lean for both groups, but it was greater for the B1 athletes. In fact, during the entire stride, both B1 and B3 athletes were leaning backward. At toe-off (TO), B1 athletes had a -3.74° backward lean whereas B3 athletes had a $-.64^{\circ}$ backward lean. These values differ from the approximately $+9^{\circ}$ forward lean reported by Atwater (1982) and the approximately $+8^{\circ}$ reported by Armstrong and Cooksay (1983). Slocum and James (1968) contended that the trunk should be essentially erect preparatory to toe-off. Because of the backward inclination of the trunk, it was determined that the center of gravity was always behind or to the rear of the lead foot at contact for B1 and B3 athletes in relation to the base of support, thus acting as a brake.

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Knee and ankle movements were also studied by Gorton and Gavron (1987). The knee flexion was greater for B3 athletes although at TO and during the swing/thigh horizontal phase, the B1 athletes had a greater hip flexion than B3 athletes. For both groups, the ankle reached maximum plantar flexion at TO with a minimum plantar flexion at mid-stance.

Hypotheses

The purposes of this study were to analyze and evaluate selected kinematic and kinetic running parameters of recreational runners who are blind in order to acquire knowledge with which to help them maximize their running efficiency, to assist coaches and teachers in developing the desired running patterns in their students, and to develop an understanding of running to be used in preventing injuries which would secure their continuous participation and progress in recreational running.

It was hypothesized that the running gait pattern of athletes who are blind will vary from that of normal recreational runners. More specifically, the hypotheses of this project were:

Hypothesis 1

The stance phase of B1 recreational runners will be longer than that of sighted recreational runners (S).

Hypothesis 2

B1 recreational runners will have a shorter normalized stride length relative to percent height compared to that of S runners.

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Hypothesis 3

- i. During running, recreational runners who are blind will demonstrate a greater degree of head and trunk inclination from the vertical than that demonstrated by the S runners.
- ii. During running, the angle between the head and the neck will be greater for S runners than it will be for recreational runners who are blind.
- iii. Recreational runners who are blind, when they run, will demonstrate less hip flexion and extension at foot strike and toe-off, respectively, when compared to S runners.
- iv. Recreational runners who are blind will have less knee flexion and extension at foot strike than S runners.
- v. Recreational runners who are blind, when they run, will demonstrate similar degrees of plantar flexion at foot strike and toe-off as S runners.

Hypothesis 4

- i. During running, recreational runners who have lost their sight before the age of five years (BB) will demonstrate a lesser degree of head and neck inclination from the vertical than that of recreational runners who have lost their sight after the age of five years (BA).
- ii. BB runners will experience a smaller angle between the head and neck compared to that experienced by the BA runners.
- iii. During running, hip flexion and extension at foot strike and toe-off, respectively, will be the same for recreational runners who have lost their sight regardless of the age at onset of blindness.

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- iv. Knee flexion and extension at foot strike and toe-off, respectively, will be the same during running for recreational runners who have lost their sight regardless of the age at onset of blindness.
- v. Plantar flexion at foot strike and toe-off during running will be the same for the recreational runners who are blind, regardless of the age at onset of blindness.

Hypothesis 5

- i. Recreational runners who are blind will experience greater peak vertical GRF Z values when they run than S runners.
- ii. Recreational runners who are blind will experience greater peak anterior-posterior GRF Y values when they run than the peak anterior-posterior GRF values experienced by S runners.
- iii. Recreational runners who are blind will experience greater peak medio-lateral GRF X values when they run than those experienced by S runners.
- iv. The rate of loading, i.e., the ratio Peak Force (F_z) to time (T) to reach this peak force (F_z), for the runners who are blind will be greater than that reported in the literature for S runners.

Hypothesis 6

- i. BB runners will experience greater peak vertical GRF Z values during running than the BA runners.
- ii. BB runners will experience greater peak anterior-posterior GRF Y values when they run than those experienced by BA runners.
- iii. BB runners will experience greater medio-lateral GRF X values when they run than those experienced by BA runners.

Hypothesis 7

- i. S runners will experience the same peak vertical GRF Z values both when they run with the use of the guide cable (SC) and when they run without the use of the guide cable (S).
- ii. SC runners will experience the same peak anterior-posterior GRF Y values as S runners.
- iii. SC runners will experience the same peak medio-lateral GRF X values as S runners.
- iv. The rate of loading, i.e., the ratio Peak Force (Fz) to time (T) to reach this peak force (Fz), for S runners will be the same as SC runners.
- iv. S runners will demonstrate the same degree of head and trunk inclination from the vertical as SC runners.
- v. The angle between the head and the neck will be the same for S runners and SC runners.
- vi. S runners and SC runners, will demonstrate the same amount of hip flexion and extension at foot strike and toe-off, respectively.
- vii. S runners and SC runners will have the same amount of knee flexion and extension at foot strike.
- viii. S runners and SC runners will demonstrate the same degree of plantar flexion at foot strike and toe-off.

Hypothesis 8

- i. SC runners and blindfolded recreational runners (SB) will experience the same peak vertical GRF Z values.
- ii. SC runners and SB runners will experience the same peak anterior-posterior GRF Y values.

- iii. The same peak medio-lateral GRF X values will be experienced by SC runners and SB runners.
- iv. The rate of loading, i.e., the ratio Peak Force (F_z) to time (T) to reach this peak force (F_z), for SC runners will be the same as for SB runners.
- v. SC runners and SB runners will demonstrate the same degree of head and trunk inclination from the vertical.
- vi. The angle between the head and the trunk will be the same for SC runners and SB runners.
- vii. The same amount of hip flexion and extension at foot strike and toe-off, respectively, will be demonstrated by SC runners and SB runners.
- viii. SC runners and SB runners will have the same amount of knee flexion and extension at foot strike.
- ix. The same degree of plantar flexion at foot strike and toe-off will be demonstrated by SC runners and SB runners.

CHAPTER III

METHODS

The primary purpose of this study was to evaluate biomechanically the running patterns of B1 recreational runners. A secondary purpose was to investigate the effect of the age at onset of blindness on running patterns. Many runners who are blind are assisted either by a person or by a device when they are engaged in recreational running. It was thought desirable, therefore, to investigate the effect of an assistive device, such as a guide cable, on the running technique. For that reason, sighted subjects were included in the study.

Subjects

The subjects in this study included five males who were blind and classified B1 according to USABA criteria, and two sighted males without uncorrectable visual impairment. No B1 female subjects were available for inclusion in the study.

Selection Criteria

Two adult male recreational runners/joggers who were blind and who lost their sight before the age of five years (BB); three adult male recreational runners/joggers who were blind and who lost their sight after the age of five years (BA); and two adult male recreational runners/joggers without any uncorrectable visual impairments (S) were selected for this study. The ages of the two BB subjects were 42 and 38 years. The three BA subjects were 47,

38, and 37 years old. The ages of the two S subjects were 36 and 38 years. All subjects were free of injuries and had no orthopedic problems. In addition, the subjects who were blind had no other disabilities. Although not representative of the entire population of males who are blind or who are sighted, the subjects were believed to be typical examples of adult males who are either blind or sighted and who participate in recreational running. The runners who were blind were classified as B1 athletes. Information about individual running speeds was not collected. All of the subjects currently ran between 8 and 16 km (5-10 miles) each week, depending on the weather. If the weather conditions were inappropriate for running outdoors, they rode an exercise bicycle. All of the subjects, but one in the BA category, ran competitively when they were younger. Although currently they are purely recreational runners, as defined in Chapter I, they still compete occasionally when their schedules permit. The subject who did not have competitive running experience ran in the past as part of his every day training for wrestling. The rest of the subjects who were blind had won medals in the past through participation in USABA track and field competitions.

Selection Methods

The Office of Programs for the Handicapped at Michigan State University was contacted to obtain the names of people who could meet the selection criteria. A screening was completed by the Director of the Office of the Programs for the Handicapped to identify individuals who met the selection criteria and who were

interested in participating in the study. Subsequently, this researcher was given a list of names and telephone numbers of potential subjects.

The list consisted of 14 subjects. Three subjects fell under the BB category, and eight subjects fell under the BA category. All these subjects would be classified as B1 according to USABA criteria. The remaining three subjects were eliminated during a telephone conversation in which the investigator indicated that a physician's report to verify the degree of their blindness would be a requirement to participate in the study. One of the three subjects in the BB subgroup was eliminated when he mentioned during a telephone conversation that he had a recent accident that resulted in a sprained ankle. Consequently, two BB subjects remained for the study. Three BA subjects were selected at random from the list of eight names provided. All the subjects who were contacted were informed that they were required to be free from any other disabilities.

The two sighted subjects were male volunteers and acquaintances of the investigator. Care was taken to assure that the sighted individuals had similar ages, and similar running experiences, to those of the subjects who were blind. They had some competitive running experience when they were younger, but currently they were recreational runners. An attempt was made to avoid pre-adult and elderly subjects to control for the influence of maturation and aging processes on running technique.

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Informed Consent Procedures

The subjects who were blind were initially informed about the study by the Director of the Office of Programs for the Handicapped. Subsequently, the researcher called the subjects to provide additional information about the study. They were assured that the results of the study would be confidential, and that they would be identified by number only and not by name. They were also informed that they could withdraw from the study at any time. An information letter and a consent form (see Appendix A) were written by this researcher, and then printed in Braille by the Department of Programs for the Handicapped. The Braille forms were then mailed to the subjects. The subjects were asked to sign the consent form as proof of their willingness to participate in the study. The researcher then contacted the subjects by telephone to answer any additional questions they might have regarding their participation. The dates for orientation and testing were determined in consultation with the subjects. They were requested to bring their signed consent forms on their first visit to the testing site.

The subjects who were sighted were informed about the study by the author. The researcher assured them that the results of the study would be kept confidential and that they would be identified by number only. They were told that they could withdraw from the study at any time. The information letter and consent form were mailed to the sighted subjects. They were asked to sign the consent form as proof of their willingness to participate in the project. Since the investigator was in touch with these subjects regularly, he could answer any additional questions they might have regarding

their participation in the study. The dates for the orientation and testing of the sighted subjects were scheduled. They were reminded to bring their signed consent form with them on their first visit to the testing site.

Instrumentation and Physical Arrangement

The layout of the testing environment is presented in Figure 3.1. The laboratory area included an anthropometric station for obtaining measures of the subjects' height, weight, and limb length; and for applying the body markers. A motorized treadmill was used for warm-up and to determine metronome speed for each subject. An 18 m runway, with a force plate set flush with the floor, positioned approximately 9 m from the starting line, was located near the west wall of the laboratory area. A metronome was situated 2 m past the force plate at the inside of the runway. A rope was taped to the floor at the beginning of the runway to serve as a starting line. A 16 mm Locam camera loaded with a 125 ASA Kodak Ektachrome film 7242 Tungsten, was positioned approximately 6 m from the runway, perpendicular to the plane of movement, and in line with the force plate. A trained observer was positioned next to the camera. Also, before data collection began, a meter stick was filmed to permit subsequent linear conversion of filmed images. At the end of the runway, a pole-vault mat was attached to the wall to provide safety in case a subject did not slow down when he ran past the metronome or if he did not hear the spotter who was positioned in front of the mat telling him to slow down and stop. The distance from the force plate to the mat was approximately 9.5 m. A guide cable containing

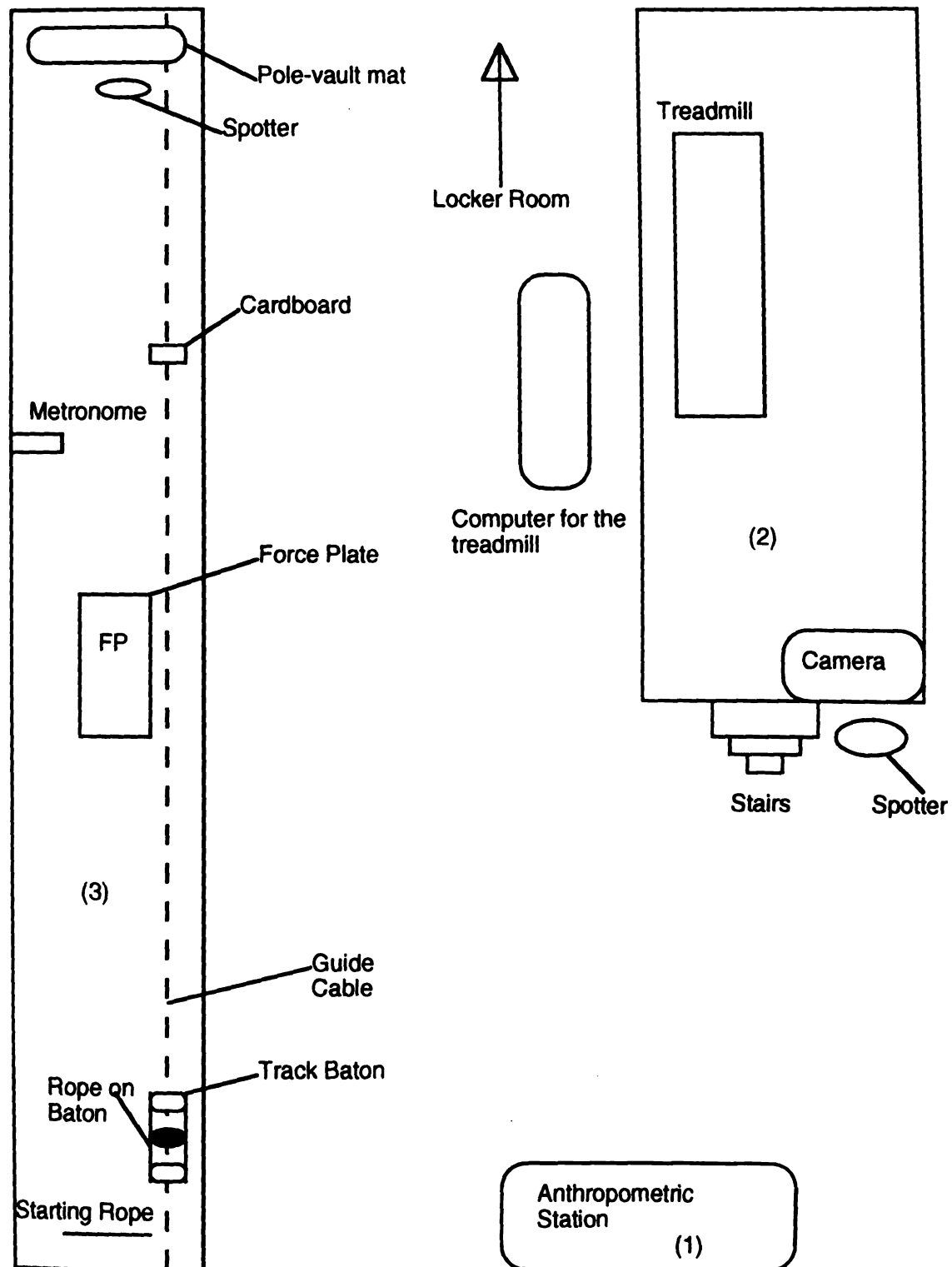


Figure 3.1
Layout of laboratory area. (The numbers indicate the sequence of activities and where these activities took place.)

a track baton with a 50 cm rope attached to the baton was positioned along the right side of the runway approximately at the height of the subject's hip. A piece of cardboard was positioned on the cable approximately 6 m from the end of the runway to provide resistance to the sliding baton and serve as an additional cue for the subject to stop running.

Procedures for Data Collection

The subjects were tested in the Center for the Study of Human Performance at Michigan State University. Each subject visited the laboratory twice.

First Visit

During the first visit, the subjects familiarized themselves with the laboratory layout by walking around the laboratory area while they were given a basic orientation. During the orientation, the subjects were given specific information about the nature and location of the testing equipment (for technical information about the equipment see Appendix B) as well as the testing procedures.

When walked to the treadmill, the subjects who were blind were told that, in order to get on the platform containing the treadmill for their warm-up, they needed to go up three stairs. Once on the treadmill platform, the subjects were given the option of familiarizing themselves with the treadmill. If they chose to do so, the warm-up protocol for their second visit was used (see "Second Visit"). In addition, they were given the option of some practice runs on the runway to familiarize themselves with the guide cable and the runway. The procedures followed were the same as those used on their second visit (see "Second

Visit"), but without the camera and metronome in operation. At the end of the orientation visit, the subjects who were blind were briefly interviewed to collect information about the age at the onset of their blindness, the degree and the cause of their blindness, and their running history (see Appendix C for the "Activity History Form"). The two subjects with normal vision were interviewed concerning their running history.

Second Visit

The anthropometric and running data were collected during the second visit. The force plate was calibrated before each subject came to the laboratory. When the subject came into the laboratory, he changed into his running gear. He wore running shorts so that leg movements were not constrained; a light, sleeveless top so that the arm swings were not limited; and, jogging/running shoes free of any orthotic devices that might alter his natural running gait. The use of shoes with no orthotic devices allowed the investigator to make comparisons among the subjects as well as with information already existing in the literature. Anthropometric measurements were then taken (see Appendix D). Each subject's height and lower limb length were measured using the techniques described by Gordon, Chumlea Cameron, and Roche (1988) to permit calculation of stride length as a percent of standing height and of lower limb length. Each subject's weight was also measured so that the ground reaction force (GRF) could be reported in terms of the subject's body weight (BW).

Prior to warm-up and collection of the running data, self-adhesive circular discs (1.5 cm in diameter), were positioned on body landmarks

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on the subject's right side. The body markers were placed: (a) on the side of the head directly superior to the corner of the jaw near the vertex of the head (on a swimming cap worn by the subject), (b) on the angle of the jaw, (c) at the level of the seventh cervical vertebra and in line with the markers near the top of the head and angle of the jaw, at the center of the neck, (d) at the center of the shoulder, (e) on the greater trochanter of the femur, (f) at the center of the knee joint, (g) on the center of the lateral malleolus of the ankle, and (h) on the lateral metatarsals (see Appendix E). After the body markers were applied, the subject proceeded to the treadmill for warm-up. Two spotters assisted the subject up the stairs. Individual preparations for exercise, such as stretching, were respected and allowed before the actual treadmill warm-up was begun.

The treadmill warm-up period was approximately 5 minutes in duration. The treadmill was operated by a qualified individual who was assisting with the project. The treadmill speed started at a slow walking pace (e.g., 0.5 m/s), and then progressed in 0.5 m/s increments every 30 s until the desired testing speed of 3.5 m/s (8 min/mile) was reached. This speed was maintained for 2 minutes or until the subject felt comfortable. This particular speed was selected since it had been established in the literature as the normal jogging speed for sighted individuals (Bates et al., 1983; De Vita & Bates, 1988; Hamill et al., 1983; Holden et al., 1985). In addition, selection of that jogging speed enabled the investigator to compare the data from this project with results reported in the literature for sighted individuals.

When the desired testing speed and a steady pace was reached, the sound of the subject's footfalls were recorded on a Sanyo micro tape

recorder . The recorded sound was used to set the speed of the metronome to the subject's own individual pace for the prescribed running speed. This procedure was considered to be appropriate because, during the warm-up period, the subject was not tired. Therefore, variations in the individual's stride were not displayed as a result of fatigue or lack of warm-up. The sound from the metronome was subsequently used to assist the subject in maintaining the same running pace for each trial. During the warm-up, the subject was spotted by the investigator and an assistant who were positioned, respectively, to the side of and behind the subject running on the treadmill.

Following the warm-up, the subjects were walked to the runway for data collection. They were reminded of the position of the starting rope at the beginning of the runway, the guide cable parallel to the runway, the metronome located past the force plate, the spotters, and the pole-vault mat at the end of the runway (see Figure 3.1). In addition, the subjects received tactile experience of the rope attached to the track baton and the guide cable threaded through the baton and strung parallel to the runway. Individuals who had not practiced during their first visit to the laboratory were permitted to walk along the runway to become familiar with the running surface and the use of the rope, cable, and baton.

The guide cable was placed on the subject's right side, at approximately hip height. The individual walked holding the rope attached to the baton. This allowed a natural swing of the upper extremity. The guide cable was used to assist the subject in moving in a straight line toward the force plate. The runners who were sighted ran both with and without the use of the guide cable so that its effect on the

running technique could be studied. The sighted subjects also ran blindfolded while using the running cable so that the effect of this condition on running technique could be studied.

The subjects heard the metronome before the data were collected so that they could memorize, or make themselves accustomed to, the pace of the sound it made. For data collection, subjects were instructed to run at the pace dictated by the metronome. They started behind the rope that was taped to the floor and used as the starting line. The runners who were blind were given the opportunity to feel the rope with their feet. The position of the rope was adjusted during the practice session until the subject could hit the force plate with the appropriate foot (right foot when data were collected for the right leg, left foot when data were collected for the left leg). The taped-down rope was used as the starting mark because the subject could feel it. The idea was that the subjects who were blind would know where to start without additional assistance and, therefore, would be provided with a sense of independence.

It was emphasized to the subjects that they should run at the desired speed "naturally" on the runway. They were informed that they could indicate any time they felt that their gait pattern was not natural. The subjects were also instructed to slow down when they felt the resistance of the cardboard on the cable or after they passed the metronome, which had the dual role of helping the subject to maintain pace at the desired speed and of providing feedback to the subject as to when the force plate had been passed. Practice runs were allowed until each subject felt comfortable with the testing procedure.

Ground reaction force data were collected on three successful trials for each foot or a total of six successful trials. The positional data for these trials were filmed with a 16 mm Locam cinematographic camera operating at 100 frames per second (fps). A trial was deemed successful when: (a) the entire foot hit the force plate, (b) the strides were natural, and (c) the runner's footfalls kept time with the metronome. The trial was discarded if lunging or short choppy steps were viewed by the trained observers, if the foot did not fall entirely on the force plate, or if the subject felt the stride was not natural. Two trained observers were used to determine the success of each trial. If there were any doubts as to the success of foot placement on the force plate, the trial was discarded. One of the observers stood in front of the mat, which was placed against the wall at the end of the runway, and the other observer stood opposite the camera on the inside of the runway facing the camera. Filming for each trial was initiated at the time the individual started running. This permitted the camera to reach a constant rate of approximately 100 fps before the subjects come into view in the area of the force plate where a movement of one complete gait cycle was photographically recorded. A schematic representation of the laboratory and of the sequential activities in which a subject was involved during the data collection session is presented in Appendix F.

The instructions to the subjects and the protocol followed were developed by the investigator following a pilot study with a visually impaired volunteer who did not have complete loss of sight (see Appendix G).

Feedback to the Subjects

At the end of the test, the subject was given verbal feedback about his performance in terms of kinematics, based upon the immediate observations by the researcher. In addition, when the results of the study were available, the researcher contacted the subjects and provided them with feedback about their running technique. The researcher informed each subject about the desired running technique as indicated by the literature for individuals who are sighted and then made suggestions, when deemed appropriate, for alterations in the subject's running pattern to improve efficiency in terms of the ground reaction forces experienced and the running posture exhibited.

Data Analysis

The X, Y and Z ground reaction forces were obtained from the data provided by the force plate. An available software program automatically graphed their histories after each trial. The information was stored and graphs were printed after data collection was completed. The respective times of the occurrence of foot strike, toe-off, mid-stance, crossover, and transition also were recorded.

Values were entered on the data collection sheet (see Appendix D). The data were normalized for each subject by his body weight. The relative time in which each event occurred was reported in terms of the percent of stance phase. The percent of stance phase for each event was determined by dividing the absolute time of the event by the absolute total time of support. The stance support time was obtained from the graphs, and was measured from the time the force plate was triggered at

foot strike until the toe was off the plate. Figures 3.2 to 3.4 indicate the parameters studied.

The parameters studied were:

- GRFz
 - a. Maximum deceleration,
 - b. Time to maximum deceleration
 - c. Percent of stance time to the occurrence of maximum deceleration
 - d. Maximum unloading
 - e. Time to maximum unloading
 - f. Percent of stance phase at which maximum unloading occurred
 - g. Maximum acceleration force
 - h. Time to maximum acceleration force
 - i. Percent of stance phase during which maximum acceleration force occurred
 - j. Total time of support
- GRFy
 - a. Initial/maximum brake force
 - b. Time to initial/maximum brake force
 - c. Percent of stance phase at which initial/maximum brake force occurred
 - d. Second/maximum brake force
 - e. Time to second/maximum brake force
 - f. Percent of stance phase at which second maximum brake force occurred
 - g. Time of transition (crossover) from brake force to propulsive force

- h. Percent of stance phase at which transition (crossover) occurred
- i. Maximum propulsive force
- j. Time to maximum propulsive force
- k. Percent of stance phase at which maximum propulsive force occurred

- GRFx
- a. Maximum medial/lateral force (according to which comes first)
 - b. Time to maximum medial/lateral force
 - c. Percent of stance phase at which maximum medial/lateral force occurred
 - d. Time of transition from medial to lateral force or the reverse
 - e. Percent of stance phase at which transition occurred
 - f. Maximum medial/lateral force
 - g. Time to maximum medial/lateral force
 - h. Percent of stance phase at which maximum medial/lateral force occurred

The kinematic patterns of the subjects were obtained by digitizing the film images of the subjects in the positions of foot strike and toe-off. The parameters studied were (see Figure 3.5):

- a. Degree of dorsi or plantar flexion (angle at the ankle)
- b. Knee angle
- c. Hip-trunk angle
- d. Angle at the elbow
- e. Angle at the shoulder

- f. Head-neck angle
- g. Inclination of the trunk from the vertical
- h. Inclination of the head from the vertical

In addition, angular positions and velocities of selected body segments and joints throughout an entire stride were determined. Values were entered on the data collection sheet (see Appendix D). Each subject's stride length was measured from the toe-off of one foot to the next toe-off of the same foot. This distance was measured from projected images of the film and then multiplied by the linear conversion factor to find the actual length. Stride length was normalized by calculating its relationship to the subject's height and leg length, expressed as percent of the subject's height and as percent of lower limb length.

Reliability of Digitized Data

One trial of a subject was digitized twice and each trial was analyzed by the Bioanalysis computer program. A Pearson product-moment correlation was calculated by the SPSSX program for the positions of the metatarsals, ankle, knee, hip, wrist, elbow, shoulder, seventh cervical, corner of the jaw, and for the landmark on the side of the head directly superior to the corner of the jaw, and near the vertex of the head, for Subject 7. The results, which appear in Table 3.1, were highly significant at the .05 level. The highest reliability coefficient was .9988 for the shoulder and the corner of the jaw in the X direction. The lowest correlation coefficient was .4959 for the seventh cervical in the Y direction.

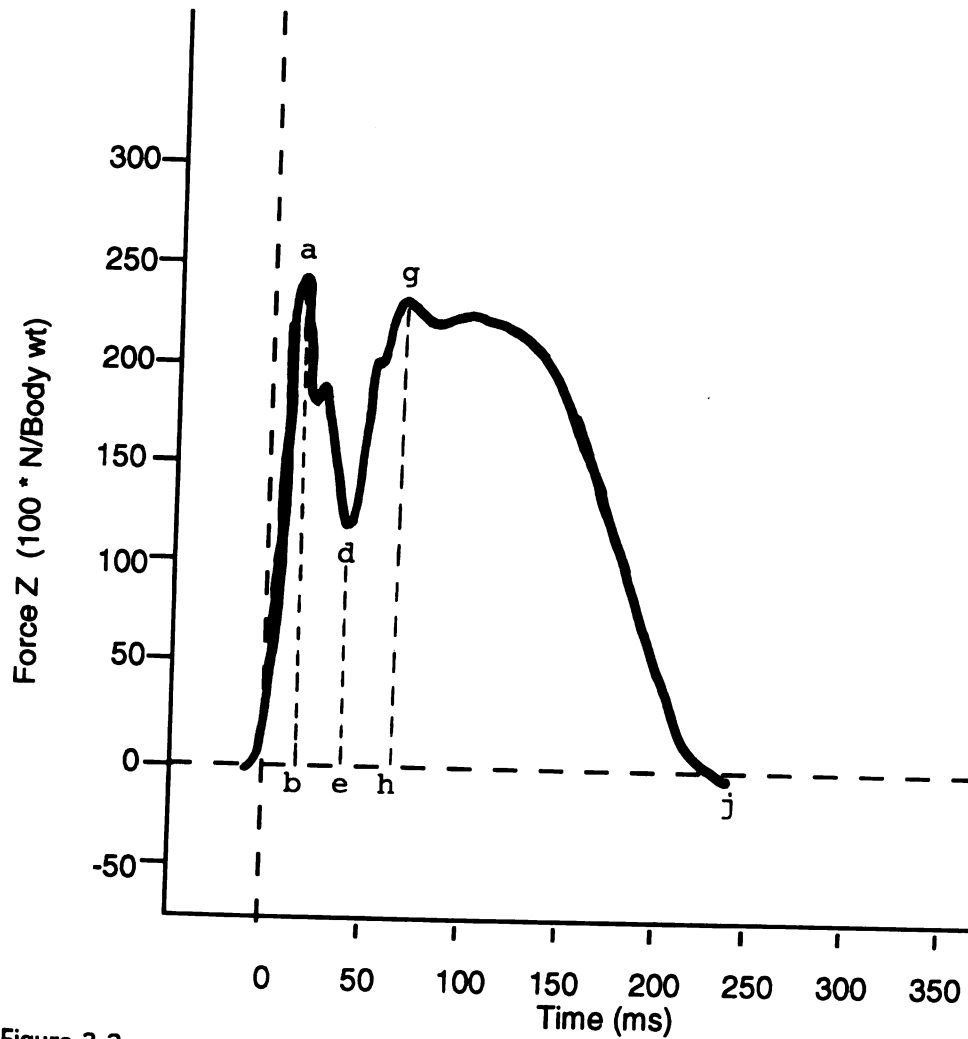


Figure 3.2

The parameters of the ground reaction force in the vertical direction: a. Maximum deceleration, b. Time to maximum deceleration, c. Percent of stance time to the occurrence of maximum deceleration, d. Maximum unloading, e. Time to maximum unloading, f. Percent of stance phase at which maximum unloading occurred, g. Maximum acceleration force, h. Time to maximum acceleration force, i. Percent of stance phase during which maximum acceleration force occurred, j. Total time of support. (The percent of stance phase that an event occurred is found by dividing the time that the particular event occurred with the total time of support.)

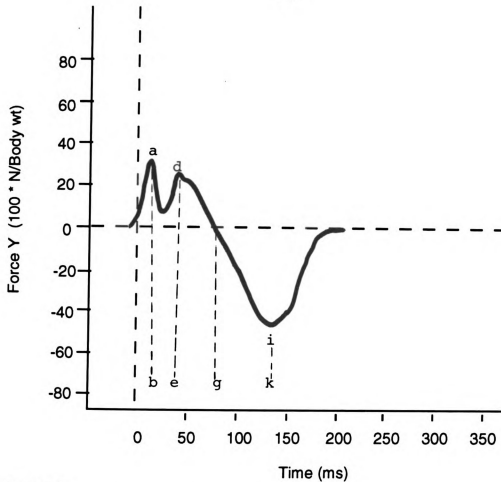


Figure 3.3

The parameters of the ground reaction force in the anterior-posterior direction:

a. Initial/maximum brake force, b. Time to initial/maximum brake force, c. Percent of stance phase at which initial/maximum brake force occurred, d. Second/maximum brake force, e. Time to second/maximum brake force, f. Percent of stance phase at which second maximum brake force occurred, g. Time of transition (crossover) from brake force to propulsive force, h. Percent of stance phase at which transition (crossover) occurred, i. Maximum propulsive force, j. Time to maximum propulsive force, k. Percent of stance phase at which maximum propulsive force occurred. (The percent of stance phase that an event occurred is found by dividing the time that the particular event occurred with the total time of support.)

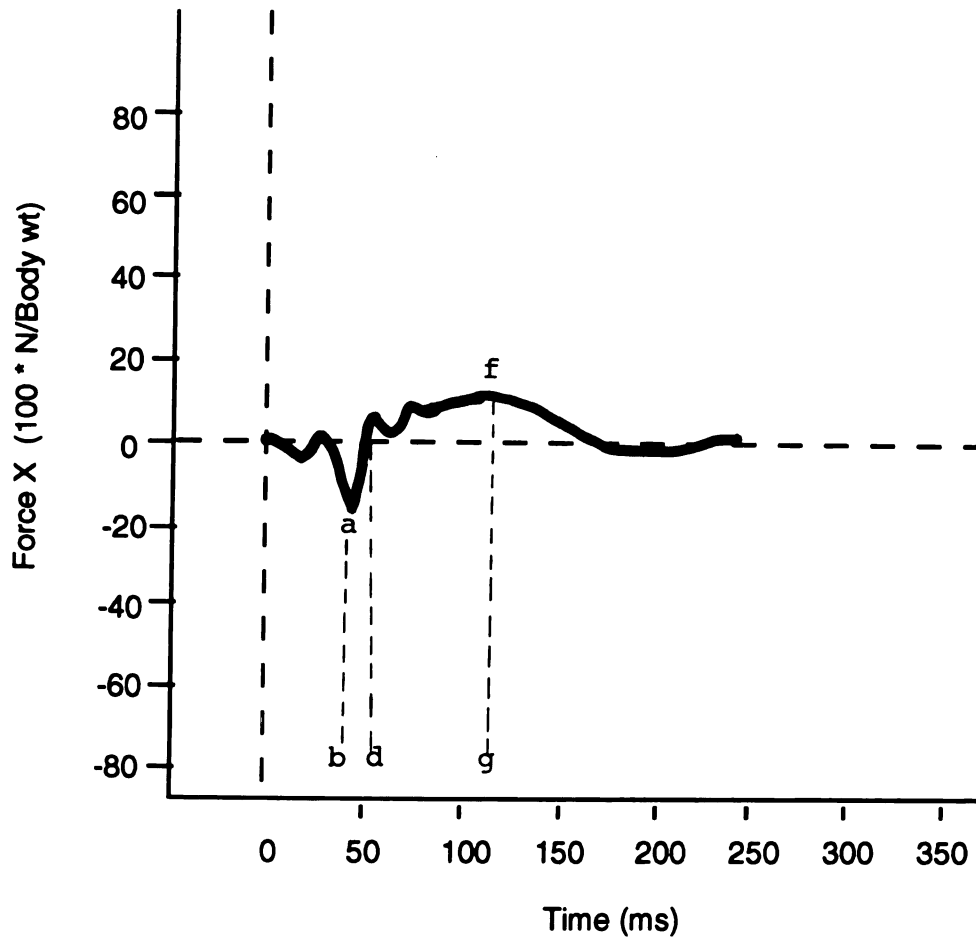


Figure 3.4

The parameters of the ground reaction force in the medial-lateral direction: a. Maximum medial/lateral force, b. Time to maximum medial/lateral force, c. Percent of stance phase at which maximum medial/lateral force occurred, d. Time of transition from medial to lateral force or the reverse, e. Percent of stance phase at which transition occurred, f. Maximum medial/lateral force, g. Time to maximum medial/lateral force, h. Percent of stance phase at which maximum medial/lateral force occurred. (The percent of stance phase that an event occurred is found by dividing the time that the particular event occurred with the total time of support.)

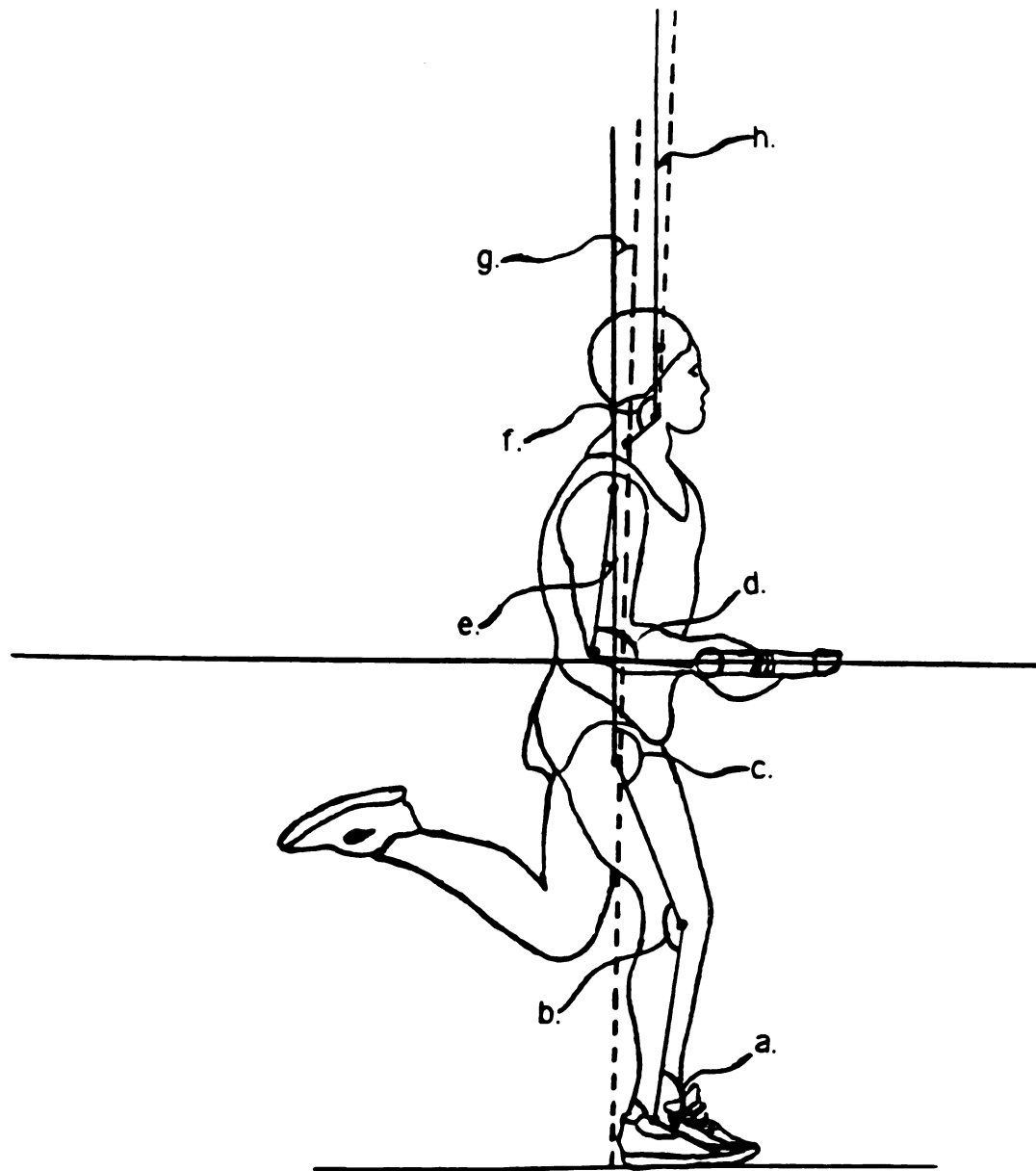


Figure 3.5
 The kinematic parameters: a. Degree of dorsi- or plantar- flexion (angle at the ankle),
 b. Knee angle, c. Hip-trunk angle, d. Elbow angle, e. Shoulder angle, f. Head-neck angle,
 g. Inclination of the trunk from the vertical, h. Inclination of the head from the vertical.

Table 3.1
Reliability Correlation Coefficients for selected digitized data points.

Variables	Metatarsals	Metatarsals	Ankle	Ankle	Knee	Knee	Hip	Hip	Wrist	Wrist	Elbow	Elbow	Shoulder	Shoulder
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Table 3.1 continued							
Variables	7th	Cervical	7th	Cervical	Center	low	Top of Head

Table 3.1 continued

Variables	7th Cervical X2	7th Cervical Y2	Corner Jaw X2	Corner Jaw Y2	Top of Head X2	Top of Head Y2
7th Cervical X	.9986					
7th Cervical Y		.4959				
Corner Jaw X			.9988			
Corner Jaw Y				.5343		
Top of Head X					.9985	
Top of Head Y						.4873

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to investigate selected kinematic and kinetic variables associated with the running patterns of individuals who are blind. Seven individuals described and classified in the previous chapter were tested following the procedures outlined in Chapter III.

In this chapter, the results for each parameter studied are presented according to the subject groups. Ranges and median values for the dominant and nondominant legs are reported. The presentation of the data is followed by a discussion of the research findings as they pertain to each of the hypotheses of the study.

Results

Kinematics

Kinematic results were determined from cinematographic data. These results describe the movement of the subjects in terms of displacement, velocity, and acceleration. In this section the displacement, or positional data, of the subjects' body segments will be addressed relative to their horizontal velocity.

Horizontal Running Velocity

The digitized cinematographic data files were analyzed with a FORTRAN program (Bioanalysis) to obtain the specified kinematic information. To determine whether or not the subjects ran with the

same horizontal velocity, the velocity of each subject's run was calculated by measuring the distance covered from foot strike to foot strike as a function of time. The median horizontal velocity for each subject is noted in Figure 4.1. Table 4.1 shows the horizontal velocity ranges for all subgroups of subjects.

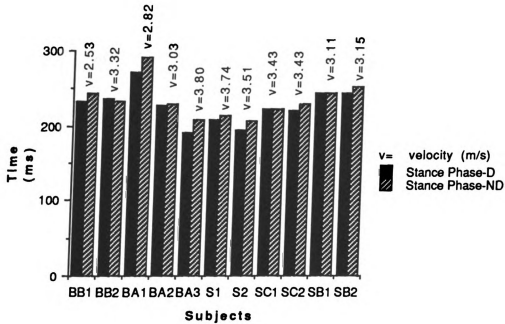


Figure 4.1
Median time values for the stance phases for the Dominant (D) and Nondominant (ND) leg for running. (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

Running speed varied across subgroups and across the subjects within each subgroup (see Appendix H). In comparison to the other subgroups, in most cases, a narrower velocity range was demonstrated by the sighted subjects under each of their running conditions. When they ran under the SC and SB conditions, their

Table 4.1
Performance range on selected kinematic parameters for all subject groups (five trials per subject).

Variables	BB (2)*	BA (3)	S (2)	SC (2)	SB (2)
Running Velocity (m/s)	2.41 - 3.80	2.77 - 3.91	3.42 - 3.81	3.36 - 3.72	2.99 - 3.29
Stance Phase (ms)					
Dominant leg	232 - 245	180 - 283	178 - 226	204 - 229	221 - 250
Nondominant leg	229 - 259	202 - 298	204 - 238	219 - 236	234 - 257
Stride Length (cm)					
First Stride					
%SHS	41 - 53	48 - 65	58 - 69	57 - 66	59 - 65
%LLL	84 - 105	98 - 130	126 - 136	119 - 133	118 - 144
Second Stride					
%SHS	42 - 51	51 - 86	61 - 77	64 - 71	58 - 69
%LLL	86 - 101	102 - 161	133 - 156	132 - 155	113 - 152

Table 4.1 continued

Variables	BB (2)	BA (3)	S (2)	SC (2)	SB (2)
Cycle Length					
%SHS	83 - 103	104 - 145	119 - 142	124 - 135	117 - 134
%LLL	170 - 205	214 - 279	260 - 284	260 - 292	235 - 296

* = In parentheses is the number of subjects per group.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

%SHS=Percent Standing Height with Shoes.

%LLL=Percent of Lower Limb Length.

velocity range was even narrower than when they ran under the S condition. The median horizontal velocity values of the sighted runners were similar across all three running conditions (see Figure 4.1).

Stance Phase

Times for stance phase varied within and between subgroups (see Table 4.1 for the subgroup ranges, Figure 4.1 for the medians of individual subjects, and Appendix I for the individual performances). The median times for the stance phases for both the dominant and nondominant legs of the BB subjects were longer than those of subjects BA2 and BA3, but were not longer than those of BA1. Even when BB2 ran faster than BA2, BB2 had the tendency to demonstrate a longer stance phase (Appendix I and Figure 4.1). Most of the trials in Appendix I indicate this tendency of the BB subjects to have longer stance phases than the BA subjects. In comparison to the other subgroups, the BB subjects had the narrowest stance phase range for the dominant leg (Table 4.1). Under all running conditions the recreational runners with no visual characteristic had the shortest stance phase range for the nondominant leg in comparison to the other subgroups. The S subjects had the lowest median for the dominant and nondominant leg among all subjects except BA3. This trend can be confirmed by most of the trials that show the individual performances of the relevant subjects in Appendix I. In addition, it can be observed in Appendix I that most of the stance phases of the SC subjects were shorter than those of the BB and BA subjects, except for BA3. The median stance phase times of the SC subjects, however, were longer than those of the S subjects. This trend can be confirmed by most of the individual performances of the relevant subjects in Appendix I. However,

the numerical values of these results may not be representative of a constant velocity of running because the sighted subjects may still have been accelerating. When the sighted subjects ran under the SB condition, they experienced their greatest median stance phase time (Figure 4.1). This trend is also reflected on most of the individual performances of the relevant subjects in Appendix I. Furthermore, the data in Appendix I indicate the tendency for each of the sighted subjects to progressively increase his stance phase times relative to the previous running condition: first, they ran under the S running condition; second, they ran under the SC running condition; and third, they ran under the SB running condition.

Stride Length

Stride length for two consecutive strides was calculated for each subject as a percent of his standing height with shoes (%SHS) and without shoes (%SHNS), and as a percent of his lower limb length (%LLL). The results for %SHNS are not reported because they differ negligibly from %SHS. Table 4.1 shows that the ranges of the first and second stride lengths of both the BB and the BA runners overlap (see Appendix J). The first stride length of the S and SC subjects was in most cases shorter than, and in some cases equal to, the second (see Appendix J). The ranges of the %SHS were narrower (i.e., the numerical values were closer) for the sighted subjects when they ran under the SC, and SB conditions than when they ran under the S condition (see Table 4.1). The median stride lengths in relation to lower limb length are presented in Figure 4.2. The relationship between the length of the first and second stride is

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consistent for the sighted subjects, i.e., the first stride was smaller than the second, but it was not consistent for the BB and BA runners.

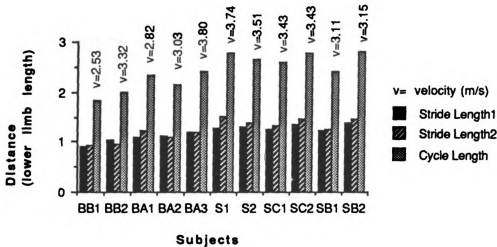


Figure 4.2

Median values for cycle lengths and for the first and second filmed stride lengths measured in units of lower limb lengths for running. (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

Cycle Length

The cycle length as a percent of standing height with shoes (%SHS) and lower limb length (%LLL) for each subject was calculated because it represents the combined effect of both legs. These measures represent anthropometric standardizations that permit direct comparisons of subjects who differ in their actual height (see Table 4.1 for the group ranges, Table 4.2 for the medians and ranges of individual subjects, and Appendix J for the individual performances). The shortest cycle length in terms of %SHS and %LLL was performed by the BB subjects (see Table 4.2). However, the velocity at which the BB subjects ran was not related

to the relative cycle length when compared to the BA subjects. That is, in the trials that the BB subjects ran faster than the BA subjects, the percent cycle lengths of the BB subjects would be expected to be greater than the percent cycle lengths of the BA subjects. However, the subjects in the BA subgroup consistently had the greater percent cycle lengths, even in the trials in which they ran slower (see Appendix H for velocity, and Appendix J for individual cycle length performances).

The sighted subjects, under both the S and the SC conditions, on most of their trials, demonstrated the greatest percent of cycle length among all subject groups, even when their velocity was comparable to that of the other subject groups. Notable exceptions are BA3's Trial 1 and BA2's Trials 4 and 5 (see Appendix J). However, the performance of both S1 and S2 differed under the S and SC conditions. S1's cycle length performance decreased when he ran with the use of the guide cable, whereas, S2's performance increased when he ran with the cable. When the sighted subjects ran under the SB condition, their velocity dropped. Their cycle length was also reduced. This reduction in cycle length was most obvious between SC1 and SB1 (see Appendix J). The performance of the SB subjects was comparable to that of the BA subjects, but their percent cycle length still was greater than the percent cycle length of the BA subjects for the majority of the trials (see Appendix J and Table 4.2). Tables 4.3 through 4.9 document the positions of each subject's body segments at different stages of the stance phase (foot strike, mid-stance, and toe-off). The parameters that were calculated have been presented in the methods chapter, and they are depicted in Figure 3.5.

Table 4.2

Ranges of velocities, and cycle lengths expressed as percent of standing height with shoes (%SHS) and lower limb length (%LLL) for five trials.

Subjects	Velocity	Cycle Length	
	(m/s)	%SHS	%LLL
BB1	2.41 - 3.80 (2.53)*	83 - 95 (91)	170 - 191 (183)
BB2	3.32 - 3.60 (3.32)	96 - 103 (102)	190 - 205 (200)
BA1	2.77 - 2.95 (2.82)	109 - 117 (116)	221 - 241 (234)
BA2	2.78 - 3.65 (3.03)	104 - 133 (109)	208 - 267 (217)
BA3	3.05 - 3.91 (3.80)	118 - 145 (121)	237 - 279 (241)
S1	3.52 - 3.81 (3.74)	137 - 142 (141)	271 - 284 (279)
S2	3.42 - 3.60 (3.51)	119 - 124 (123)	260 - 271 (268)
SC1	3.39 - 3.72 (3.43)	128 - 132 (130)	260 - 264 (262)
SC2	3.36 - 3.53 (3.43)	124 - 135 (128)	271 - 292 (278)
SB1	3.04 - 3.29 (3.11)	117 - 129 (121)	235 - 260 (242)
SB2	2.99 - 3.24 (3.15)	126 - 134 (128)	276 - 296 (281)

* = Median values are in parentheses.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

Ankle Joint

All subjects who were blind had the ankle of their support foot in a plantar flexed position at foot strike (see Table 4.3 for the angle ranges at the ankle, and Figure 4.3 for a graphical representation of the medians of the medians). Only subject BA1 demonstrated a dorsi-flexed position at foot strike. This occurred in only one trial (see Appendix K). The subjects within each group of blind recreational runners, BB and BA, demonstrated variable performances (see Appendix K).

In general, the sighted individuals at foot strike, under all running conditions, demonstrated for most of their trials less plantar flexion or a more of a dorsi-flexed position than the recreational runners who were blind (see Appendix K). Particularly, S1 demonstrated a dorsi-flexed position at foot strike for most of his trials under all running conditions (see Appendix K). It was also observed that the plantar flexion angles of SB2 at the ankle joint decreased compared to when he ran under the S and SC conditions. Only Trial 1 for S2 was equal to Trial 2 under the SB running condition. Subject S1, under the S and SC running conditions, was less dorsi-flexed at foot strike when compared to the SB running condition. Only the dorsi-flexion angle demonstrated in Trial 3 under the S running condition was equal to Trials 1, 4, and 5 under the SB running condition.

Foot strike was followed by the mid-stance which occurs approximately at 50 percent of the stance phase when the angle between the shank and the support foot is approximately 90° (see Table 4.3). However, this was not the case for the S and SC subjects. It will be illustrated later when the kinetic results are presented, that the subjects running under the S and the SC conditions demonstrated mid-stance

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Table 4.3

Angle ranges (in degrees) for the ankle joint during the support phase for all subjects for five trials.

Subjects	Foot Strike	Mid - Stance	Toe - Off
BB1	124 - 132 (127)*	91 - 98 (93)	123 - 138 (130)
BB2	99 - 100 (99)	89 - 91 (90)	108 - 112 (112)
BA1	83 - 125 (118)	87 - 94 (91)	132 - 142 (140)
BA2	113 - 128 (125)	90 - 94 (91)	123 - 139 (131)
BA3	106 - 110 (107)	92 - 97 (95)	140 - 146 (145)
S1	86 - 95 (89)	86 - 91 (87)	112 - 127 (116)
S2	106 - 114 (112)	90 - 96 (94)	133 - 144 (137)
SC1	87 - 93 (88)	85 - 89 (86)	111-129 (116)
SC2	112 - 116 (113)	91 - 95 (92)	138 - 151 (146)
SB1	83 - 86 (86)	89 - 91 (90)	109 - 118 (112)
SB2	104 - 106 (105)	89 - 93 (90)	136 - 142 (138)

* = Median values are in parentheses.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

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earlier compared to when they ran under the SB condition. In addition, the S and SC subjects demonstrated earlier mid-stance compared to the BB and BA subgroups.

Table 4.3 shows each subject's ranges and medians of the ankle joint angles at toe-off. Figure 4.3 shows a graphical representation of the medians. For all subjects the plantar flexion angles at toe-off were greater than those at foot strike.

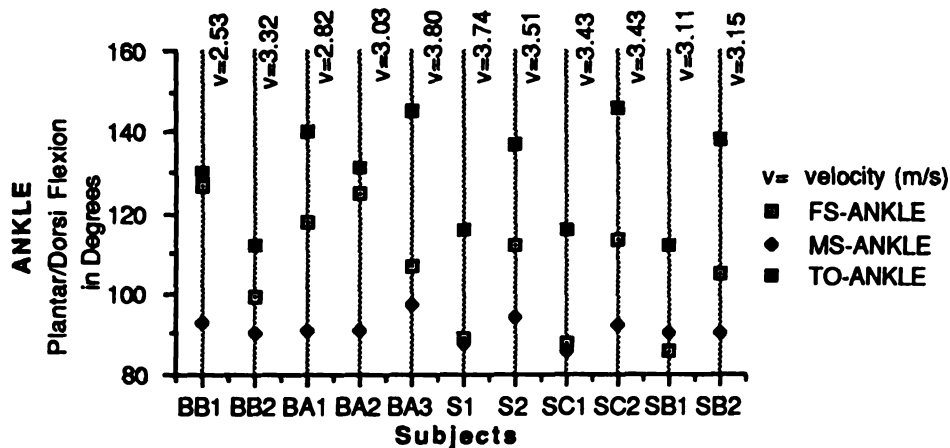


Figure 4.3

Median values of angles at the ankle during Foot Strike (FS), Mid-Stance (MS), and Toe-Off (TO) when running. (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

Knee Joint

The ranges of knee flexion of the support leg at foot strike were similar for the two groups of recreational runners who were blind (see Table 4.4 for the ranges and Figure 4.4 for a graphical representation of the medians). Although subject BA1 demonstrated more knee flexion of the support leg during foot strike than the other recreational runners, on three trials he had a flexion angle similar to the knee flexion angles of the other subjects (see Appendix L).

The subjects running under the S condition demonstrated more knee flexion at foot strike than all other subjects, and all other running

Table 4.4

Angle ranges (in degrees) for the knee joint during stance phase for all subjects for five trials.

Subjects	Foot Strike	Mid - Stance	Toe - Off
BB1	155 - 160 (155)*	142 - 151 (146)	175 - 179 (176)
BB2	151 - 154 (153)	130 - 135 (134)	132 - 153 (133)
BA1	128 - 159 (150)	132 - 135 (134)	158 - 162 (159)
BA2	153 - 161 (155)	133 - 174 (137)	154 - 162 (157)
BA3	158 - 161 (160)	130 - 142 (141)	166 - 172 (171)
S1	122 - 131 (127)	139 - 147 (141)	151 - 161 (157)
S2	140 - 150 (144)	128 - 132 (130)	155 - 169 (162)
SC1	134 - 158 (152)	133 - 139 (139)	128 - 155 (151)
SC2	145 - 153 (148)	128 - 135 (132)	165 - 171 (168)
SB1	139 - 148 (146)	127 - 135 (134)	141 - 148 (144)
SB2	150 - 158 (155)	130 - 141 (133)	164 - 171 (165)

* = Median values are in parentheses.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

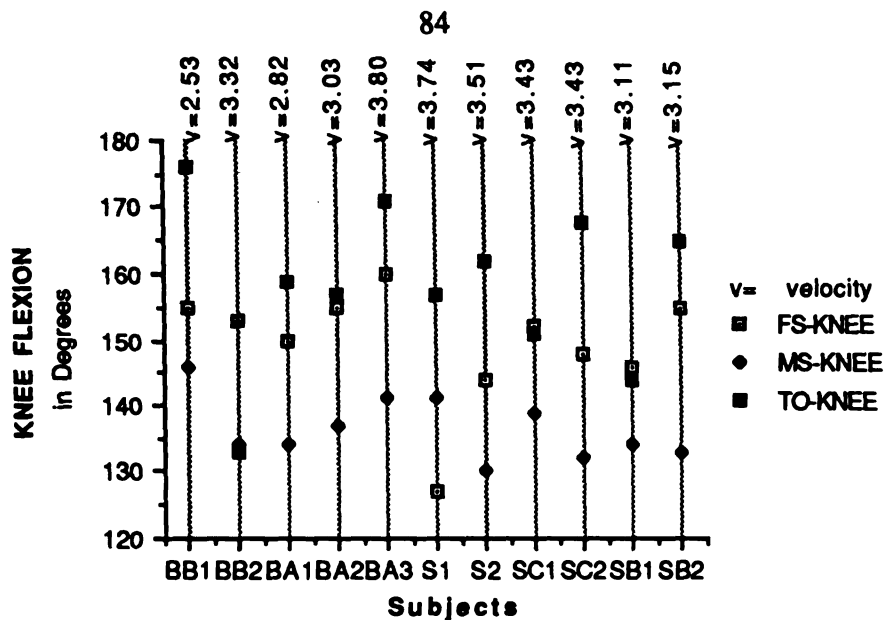


Figure 4.4

Median values of angles at the knee during Foot Strike (FS), Mid-Stance (MS), and Toe-Off (TO) when running. (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

conditions. Only Trial 2 of subject S2 was equal to Trial 3 of subject BB2, and bigger than Trials 4 and 5 of BA1. When the sighted subjects ran under the SC running condition, most trials of subject SC1 at foot strike ranged from 151° to 158°, and most trials of subject SC2 ranged from 145° to 148° (see Appendix L). Therefore, the performance of subject SC2 was similar to when he ran as S2 under the S running condition; whereas, SC1's range of knee flexion was comparable to that of the recreational runners who were blind. The situation, however, changed when the same subjects performed blindfolded. The knee flexion of the support leg at foot strike of subject SB2 ranged from 150° to 158° which was similar to those performed by the recreational runners who were blind (see table 4.4). The knee flexion of the support leg at

foot strike of subject SB1 ranged from 139° to 148°. This range demonstrated a tendency towards the performance exhibited when that subject, SB1, ran under the S running condition.

The median values of knee flexion at mid-stance of all the recreational runners who were blind were close, within a range of 134° to 146° (see Table 4.4). In particular, the ranges of knee flexion of the support leg at mid-stance of the subjects in the BA subgroup were very close to the range of knee flexion demonstrated by subject BB2. Only the knee flexion at mid-stance of Trial 1 of subject BA2 was away from the knee flexion angles he demonstrated in most of his trials (see Appendix L). When the sighted individuals ran under the SB condition, their knee flexion angles were close to those of the recreational runners in the BA subgroup, and to those of subject BB2 (see Table 4.4, and Appendix L). Subject SB2 had the tendency to flex the knee of the supporting leg at mid-stance more than when he ran under the SC and S running conditions. Furthermore, when the same subject ran under the SC running condition, he demonstrated at mid-stance of the support leg more knee flexion than when he ran under the S running condition (see Table 4.4, Figure 4.4, and Appendix L). The performance of subject SB1 was opposite than the performance of subject SB2. Subject SB1 had the tendency to flex at the knee progressively less as he ran under the S running condition first, then under the SC running condition, and under the SB running condition last (see Figure 4.4, Table 4.4, and Appendix L). However, the knee flexion angles of his support leg at mid-stance were very similar when he ran under the S and SC running conditions.

The knee extension angle at toe-off was variable across the subjects who were blind. This variability is better illustrated by the

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medians (see Table 4.4, and Figure 4.4 for a graphical representation of the medians).

Hip Joint

The ranges of hip flexion of the support leg at foot strike were similar for almost all the recreational runners who were blind and for subject S2, under all three running conditions (see Table 4.5). The performance of subject BA1, and the performance of subject BB2 in Trial 3 were the only exceptions to this observation (see Appendix M). Only subject BA1 demonstrated more hip flexion than the other subjects who were blind. With the exception of subject BA1, subject S1 demonstrated more hip flexion than all the other subjects under all the running conditions that he ran (see Table 4.5).

The hip flexion angles increased from foot strike to mid-stance for most of the subjects (see Table 4.5 for the ranges and the medians, Figure 4.5 for a graphical representation of the medians, and Appendix M for the individual performances). That means that the hip was less flexed at mid-stance.

Exceptions to this finding were seen in subjects BB2, who presented decreased angles, therefore more flexion, and BA3. Subject BA3 in Trials 1 and 3 demonstrated increased flexion at the hip joint. In Trials 2 and 4 he demonstrated decreased hip flexion, thus moving to a more flexed position relative to foot strike, whereas in Trial 5 his hip flexion at foot strike and at mid-stance was the same (see Table 4.5, and Appendix M). In addition, subject S2 in Trial 2, and subject SC2 in Trial 5 demonstrated a decreased hip flexion angle at mid-stance indicating a

Table 4.5

Angle ranges (in degrees) for the hip joint during the stance phase for all subjects for five trials.

Subjects	Foot Strike	Mid - Stance	Toe - Off
BB1	151 - 158 (157)*	152 - 163 (158)	187 - 212 (191)
BB2	144 - 156 (153)	139 - 154 (150)	184 - 196 (185)
BA1	129 - 141 (139)	154 - 163 (162)	186 - 194 (187)
BA2	152 - 162 (156)	165 - 173 (167)	196 - 199 (196)
BA3	155 - 162 (159)	150 - 166 (160)	189 - 194 (194)
S1	116 - 124 (119)	154 - 157 (155)	170 - 175 (171)
S2	149 - 161 (150)	153 - 162 (154)	189 - 204 (196)
SC1	133 - 147 (133)	158 - 163 (161)	173 - 180 (177)
SC2	150 - 156 (152)	153 - 164 (159)	198 - 201 (199)
SB1	133 - 138 (135)	154 - 164 (160)	171 - 180 (179)
SB2	153 - 160 (155)	164 - 177 (168)	197 - 204 (201)

* = Median values are in parentheses.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

more flexed position at the hip of the support leg relative to foot strike (see Appendix M).

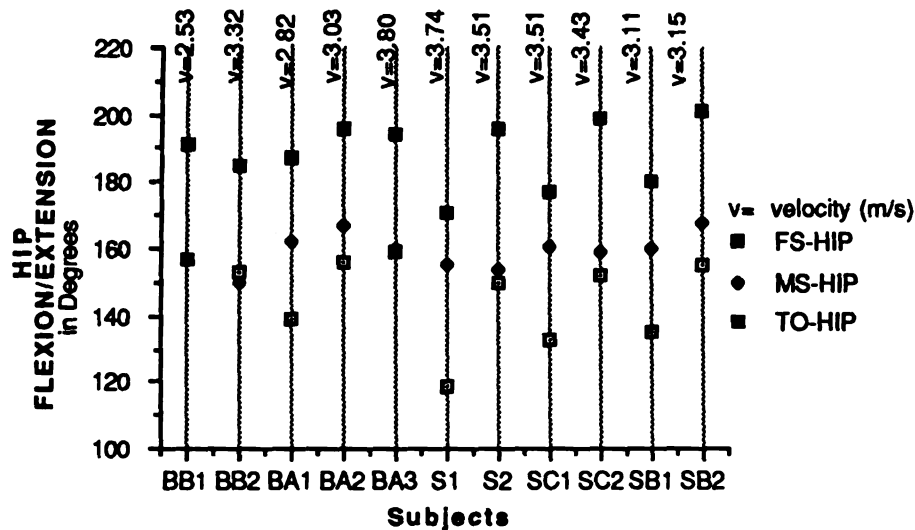


Figure 4.5

Median values of angles at the hip during Foot Strike (FS), Mid-Stance (MS), and Toe-Off (TO) when running. (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

At toe-off the hip joint hyperextended for all subjects, except S1, under all running conditions (see Table 4.5 for the ranges, Figure 4.5 for a graphical representation of the medians, and Appendix M for the individual performances). The hip ranges and medians of extension angles were very similar for all the recreational runners who were blind. Only in subject's BB1 Trial 3 the angle at the hip of the support leg was off from his overall performance and the performances of the other subjects who were blind (see Appendix M). The hip angle ranges at toe-off were consistent among all running conditions for subject S2. He tended to have the largest hip extension angles compared to most trials for the rest of the subjects (see Appendix M). In contrast, subject S1

just extended fully at the hip joint in some trials during toe-off under all three running conditions (see Appendix M).

Trunk

The ranges of the angles of the inclination of the trunk measured for each subject during the stance phase are presented in Table 4.6. The sign (+,-) indicates the position of the trunk relative to the horizontal. Plus indicates that the trunk is inclined towards the direction of movement. Minus indicates that the trunk is inclined opposite to the direction of movement. The value indicates the degree of trunk inclination from the vertical.

All but one of the recreational runners who were blind demonstrated negative inclination of the trunk at foot strike (see Table 4.6 for the ranges and medians, and Figure 4.6 for a graphical representation of the medians). When the sighted subjects ran under the S running condition they demonstrated, almost consistently, positive trunk inclination at foot strike. Only subject S2 in Trials 1 and 2 demonstrated negative trunk inclination (see Appendix N). The performances of the sighted subjects were opposite when they ran under the SC condition (see Table 4.6). Subject SC2 demonstrated negative trunk inclination at foot strike consistently. Subject SC1 in most of his trials demonstrated a positive trunk inclination at foot strike (see Appendix N). Under the SB condition, subject SB1's inclination of the trunk from the vertical decreased, getting closer to the vertical. Subject SB2's, however, inclination of the trunk at foot strike increased to the negative direction (see Table 4.6, and Figure 4.6).

Table 4.6

Trunk lean ranges (in degrees) from the vertical during stance phase for all subjects for five trials; the plus sign indicates position towards the direction of movement (medians in parentheses).

Subjects	Foot Strike	Mid - Stance	Toe - Off
BB1	(-4) - (+0) (-3)	(+11) - (+14) (+11)	(+12) - (+20) (+14)
BB2	(-4) - (+2) (-3)	(+2) - (+10) (+6)	(+2) - (+7) (+6)
BA1	(+2) - (+8) (+4)	(+17) - (+22) (+21)	(+18) - (+26) (+22)
BA2	(-8) - (-4) (-5)	(+2) - (+7) (+6)	(+5) - (+10) (+9)
BA3	(-6) - (-1) (-4)	(+7) - (+9) (+8)	(+15) - (+18) (+16)
S1	(+20) - (+23) (+21)	(+31) - (+37) (+35)	(+32) - (+37) (+34)
S2	(-10) - (+4) (+2)	(-4) - (+10) (+6)	(+9) - (+17) (+13)
SC1	(-3) - (+9) (+8)	(+22) - (+27) (+26)	(+20) - (+26) (+24)
SC2	(-7) - (-2) (-5)	(+3) - (+9) (+5)	(+10) - (+15) (+13)
SB1	(+4) - (+7) (+5)	(+16) - (+19) (+19)	(+16) - (+21) (+20)
SB2	(-10) - (-8) (-9)	(-2) - (+5) (0)	(+7) - (+10) (+8)

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

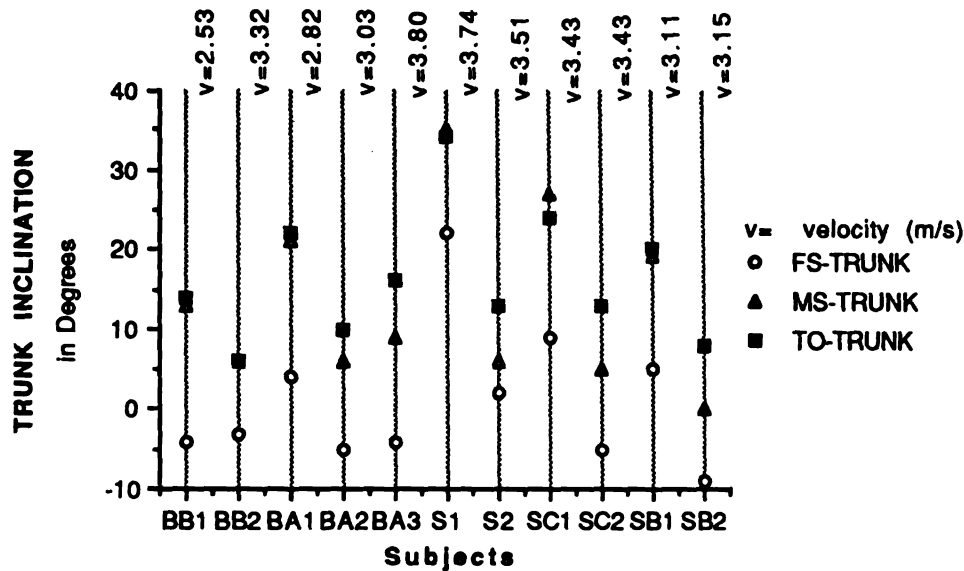


Figure 4.6
Median values of the inclination of the trunk from the vertical during Foot Strike (FS), Mid-Stance (MS), and Toe-Off (TO) when running. (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

At mid-stance, the inclination of the trunk from the vertical was positive for all the recreational runners who were blind . The degree of inclination was variable. What was noticed, however, was that the subject who ran with the lowest speed in each of the two subgroups of the recreational athletes who were blind demonstrated the largest degree of positive trunk inclination. Subject S1 continued to have the biggest trunk inclination at mid-stance among all groups when he ran under the S and SC running conditions. However, when he ran under the SC condition, the trunk inclination decreased, and when he ran under the SB running condition, the degree of trunk inclination decreased even more. Subject S2's trunk inclination at mid-stance was positive for most of his trials. Only in Trial 1 did he demonstrate negative trunk inclination (see Appendix N). When he ran under the SC condition his trunk inclination from the vertical, in general, decreased (see Appendix

N). When he ran under the SB running condition his trunk inclination angles decreased even more, and most of them were very close to 0° (see Appendix N).

At toe-off the trunk inclination for all the recreational runners who were blind, except BB2, was either profoundly increased, was increased, or it was similar, i.e., slightly increased, relative to the trunk inclination demonstrated at mid-stance (see Table 4.6 and Appendix N). When subject S1 ran under the S and SC running conditions he maintained approximately the same ranges of trunk inclination at toe-off and mid-stance for the respective running conditions. When he ran under the SB running condition, his trunk inclination angles had the tendency to decrease (see Appendix N). Subject S2 increased the inclination of his trunk from mid-stance to toe-off under all running conditions. The biggest increase of trunk inclination from mid-stance to toe-off was demonstrated when the subject ran blindfolded.

Head and Neck

The range of the angle between the head and the neck had different patterns for each subject subgroup (see Table 4.7). For the BB subgroup, the head and neck angle increased from foot strike to mid-stance and decreased from mid-stance to toe-off. Only subject BB1's Trials 2 and 4, and subject BB2's Trial 3 were exceptions to this pattern (see Appendix O). The head and neck angles between the two subjects were variable.

For the BA subjects, the head and neck angles remained approximately the same or increased less compared to the BB subgroup from foot strike to mid-stance (see Appendix O). From mid-stance to

Table 4.7

Head and neck angle ranges (in degrees) during the stance phase for all subjects for five trials (medians in parentheses).

Subjects	Foot Strike	Mid - Stance	Toe - Off
BB1	155 - 159 (157)	152 - 167 (161)	157 - 168 (159)
BB2	120 - 124 (120)	111 - 134 (125)	120 - 124 (121)
BA1	117 - 163 (125)	122 - 165 (127)	125 - 178 (142)
BA2	105 - 126 (114)	108 - 126 (115)	104 - 122 (119)
BA3	128 - 139 (135)	128 - 143 (139)	120 - 142 (141)
S1	138 - 154 (150)	140 - 149 (144)	152 - 161 (155)
S2	148 - 153 (150)	152 - 167 (155)	152 - 168 (161)
SC1	133 - 136 (134)	130 - 141 (138)	132 - 145 (134)
SC2	114 - 131 (128)	122 - 136 (131)	123 - 139 (131)
SB1	134 - 144 (140)	140 - 149 (145)	145 - 151 (149)
SB2	126 - 134 (129)	130 - 136 (132)	134 - 140 (135)

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

toe-off, the head and neck angles of the subjects in the BA subgroup increased (see Table 4.7, and Appendix O). Exceptions to this pattern were subject BA1's Trial 4, subject BA2's Trial 2, and subject BA3's Trials 1 and 2.

The sighted individuals demonstrated variable patterns of the head and neck angle range under each running condition, except when they ran blindfolded. Under the condition of SB, both subjects demonstrated with the dominant head and neck angles a progressive increase from foot strike to toe-off (see Table 4.7). Only in Trial 4 subject SB1 demonstrated the same head and neck angle at mid-stance and toe-off, and in Trial 1 subject SB2 demonstrated a decrease of the head and neck angle from foot strike to mid-stance (see Appendix O).

Head

The inclination of the head was measured for different events during the stance phase and is presented in Table 4.8. The sign indicates the position of the head relative to the direction of movement. Plus indicates that the head is inclined towards the direction of movement. Minus indicates that the head is inclined opposite to the direction of movement. The value indicates the degree of head inclination from the vertical.

The pattern of the head inclination from the vertical was different for the two subgroups of the recreational runners who were blind (see Table 4.8 for the ranges and the medians). The subjects in the BB subgroup demonstrated negative head inclination during foot strike and toe-off. Only subject BB2 in Trial 3 demonstrated positive head inclination at foot strike (see Appendix P). At mid-stance subject BB1

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Table 4.8

Range of head inclination (in degrees) from the vertical for all subjects for five trials; the plus sign indicates position towards the direction of movement.

Subjects	Foot Strike	Mid - Stance	Toe - Off
BB1	(-17) - (-13) (-15)*	(-21) - (-17) (-20)	(-23) - (-18) (-20)
BB2	(-7) - (+3) (-1)	(-10) - (+3) (+2)	(-16) - 0 (-8)
BA1	0 - (+7) (+6)	(+1) - (+13) (+2)	(+2) - (+5) (+4)
BA2	(-10) - (-4) (-5)	(-9) - (-4) (-7)	(-7) - (-4) (-5)
BA3	(+4) - (+6) (+5)	(-8) - 0 (-4)	(-3) - (-1) (-3)
S1	(+16) - (+25) (+19)	(+13) - (+21) (+17)	(+15) - (+27) (+18)
S2	0 - (+7) (+4)	(-1) - (+8) (+5)	(-4) - (+8) (+5)
SC1	(-4) - 0 (-3)	(-7) - (+1) (-7)	(-7) - (+1) (-4)
SC2	(-22) - (-17) (-21)	(-23) - (-17) (-19)	(-20) - (-17) (-19)
SB1	(+6) - (+17) (+11)	(+5) - (+20) (+8)	(+4) - (+22) (+12)
SB2	(-15) - (-9) (-13)	(-17) - (-10) (-16)	(-15) - (-9) (-12)

* = Median values are in parentheses.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

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had negative inclination of the head, whereas subject BB2 tended to have positive inclination of the head. Only subject BB2 in Trial 2 demonstrated negative inclination of the head at mid-stance (see Appendix P).

Throughout the stance phase, the head inclination from the vertical varied for the BA subjects. Subjects BA1 and BA3 had positive head inclination at foot strike. The common angle for both subjects was $+6^\circ$. Subject BA2 had a negative head inclination with a range that he maintained throughout all the events of the stance phase (see Table 4.8). At mid-stance, the inclination of the head from the vertical was negative for two of the three individuals in the BA group. The head inclination for BA1 at mid-stance was positive, but had the tendency to be less than it was at foot strike. Only subject BA1's head inclination from the vertical in Trials 1 and 3 was increased compared to foot strike (see Appendix P). The subjects who demonstrated negative head inclination during mid-stance, maintained it until toe-off (see Table 4.8). The subject BA1 demonstrated at toe-off positive inclination of the head which was, for most trials, greater than at mid-stance (see Appendix P).

The sighted subjects under the S running condition maintained approximately the same range of head inclination throughout the stance phase, but it was different for each subject (see Table 4.8). When they ran under the SC running condition, they demonstrated negative head inclination (see Table 4.8). Subject SC1 maintained the negative head inclination throughout the stance phase for all trials but one (see Appendix P). The subject SC2, however, demonstrated negative head

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inclination throughout the whole stance phase (see Appendix P). The ranges of the inclination of the head from the vertical varied among the subjects (see Table 4.8). Under the SB running condition the performance of both subjects varied. Subject SB1 demonstrated a positive range of head inclination throughout the stance phase (see Table 4.8). In contrast, subject SB2 demonstrated negative head inclination throughout the stance phase (see Table 4.8). The ranges were approximately the same during all the events of the stance phase (see Table 4.8).

Shoulder Joint

The shoulder flexion-extension angle was measured for different events during the stance phase and is presented in Table 4.9. The sign indicates the position of the arm in terms of flexion and extension, whereas the value indicates the angle, in degrees, between the trunk and the arm. The plus sign indicates flexion with the upper arm in front of the trunk. The minus sign indicates extension at the shoulder joint with the upper arm behind the trunk.

The degree of movement about the shoulder joint during the stance phase was variable among the subject subgroups. The subjects in the BB subgroup flexed their arms as a group from 9° to 28°. The subjects in the BA subgroup flexed their arms as a group from 16° to 34°. The recreational runners who were sighted performed shoulder movement ranging from 68° to 114°, 24° to 33°, and 18° to 42° when they ran under the S, SC, and SB conditions, respectively (see table 4.9 for the ranges and the medians, and Appendix Q for the individual performances).

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Table 4.9

Range of shoulder joint movement relative to the trunk (in degrees) during the stance phase for five trials. The plus sign indicates flexion and the upper arm is in front of the trunk. The minus sign indicates extension at the shoulder joint and the upper arm is behind the trunk.

Subjects	Foot Strike	Mid - Stance	Toe - Off
BB1	(-39) - (-25) (-32)*	(-20) - (-6) (-17)	(-15) - (+1) (-6)
BB2	(+3) - (+14) (+12)	(+20) - (+23) (+21)	(+19) - (+23) (+21)
BA1	(-13) - (-2) (-2)	(+9) - (+30) (+21)	(+8) - (+32) (+23)
BA2	(-26) - (-12) (-18)	(-3) - 0 (-2)	(+2) - (+4) (+2)
BA3	(-17) - (-9) (-9)	0 - (+17) (+5)	(+12) - (+24) (+15)
S1	(-62) - (-40) (-50)	(+25) - (+42) (+34)	(+35) - (+54) (+45)
S2	(-59) - (-38) (-48)	(-36) - (-8) (-12)	(+25) - (+51) (+33)
SC1	(-46) - (-35) (-41)	(-15) - (-12) (-13)	(-13) - (-10) (-11)
SC2	(-38) - (-35) (-36)	(-25) - (-12) (-20)	(-9) - (-3) (-5)
SB1	(-43) - (-29) (-38)	(-20) - (-1) (-15)	0 - (-20) (-17)
SB2	(-48) - (-13) (-24)	(-30) - (+4) (-6)	(-6) - (+12) (+9)

* = Median values are in parentheses.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

Kinetics

Kinetic results were determined from force plate data. These results describe the forces responsible for the displacement, velocity, and acceleration of the subjects while running.

Foot Strike

The three components of the ground reaction force (GRF): vertical (Z direction), anterior-posterior (Y direction), and the medio-lateral (X direction) were calculated for each subject. From visual observation of the film, it was determined that BA3 was a rearfoot striker; BB2, BA1 and BA2 were midfoot strikers, BB1 was a forefoot striker. Of the sighted subjects, S1 was a midfoot striker and S2 was a rearfoot striker.

Vertical Ground Reaction Force

The performance of each subject on selected parameters of the vertical component of ground reaction forces, for both the dominant and nondominant leg, is presented in Table 4.10 (range and median values). Figures 4.7 to 4.9 display a graphical representation of the median values for the dominant leg, whereas Figures 4.10 to 4.12 display a graphical representation of the median values for the nondominant leg.

The subjects in the BB subgroup experienced greater decelerating forces, in times BW, for the dominant leg than the BA1 and BA2 subjects who were running at comparable velocities. Moreover, maximum deceleration of the dominant leg occurred later in time and in percent stance phase for the BA1 and BA2 subjects than for the subjects in the BB subgroup. The nondominant supporting leg also experienced higher

Table 4.10
Selected performance parameters associated with the vertical component of the ground reaction force (three trials for each leg).

Subject Leg	Maximum Deceleration			Maximum Unloading			Maximum Acceleration		
	Times BW	Time (ms)	Percent Stance	Times BW	Time (ms)	Percent Stance	Times BW	Time (ms)	Percent Stance
BB 1									
Dominant	2.35-2.69 (2.46)*	27-33 (28)	11.5-13.5 (12.1)	2.03-2.31 (2.07)	44-49 (46)	19.0-20.0 (19.8)	2.42-2.54 (2.51)	68-84 (74)	28.0-36.0 (31.8)
Non- dominant	1.93-2.60 (2.50)	25-36 (28)	10.3-15.0 (11.2)	1.71-2.27 (1.96)	47-53 (48)	19.2-22.0 (19.3)	2.20-2.42 (2.22)	67-88 (67)	27.6-35.5 (27.8)
BB2									
Dominant	2.14-2.97 (2.19)	20-28 (26)	8.7-12.0 (10.9)	1.07-2.03 (1.94)	45-49 (46)	19.0-21.5 (19.5)	1.79-2.21 (2.16)	66-103 (75)	28.7-43.0 (31.8)
Non- dominant	1.99-2.76 (2.54)	22-31 (23)	9.6-12.0 (9.9)	1.35-1.40 (1.35)	43-53 (47)	19.0-20.5 (20.1)	1.82-1.85 (1.83)	90-97 (95)	37.5-40.5 (38.6)

Table 4.10 continued

Subject	Maximum Deceleration		Maximum Unloading		Maximum Acceleration	
	Times BW	Time (ms)	Times BW	Time (ms)	Times BW	Time (ms)

Table 4.10 continued

Subject Leg	Maximum Deceleration			Maximum Unloading			Maximum Acceleration		
	Times BW	Time (ms)	Percent Stance	Times BW	Time (ms)	Percent Stance	Times BW	Time (ms)	Percent Stance
BA1									
Dominant	1.61-1.97 (1.65)	47-51 (48)	17.7-19.4 (18.0)	1.59-1.89 (1.63)	54-57 (54)	19.9-22.3 (20.1)	2.13-2.28 (2.15)	127-141 (131)	48.3-52.4 (49.8)
Non-dominant	1.45-1.78 (1.48)	23-26 (25)	7.8-8.9 (8.3)	1.19-1.40 (1.30)	49-54 (51)	16.8-18.7 (17.1)	1.89-2.00 (1.97)	77-122 (118)	26.3-40.9 (40.8)
BA2									
Dominant	1.87-2.18 (2.04)	29-36 (33)	12.8-15.2 (14.8)	1.82-1.89 (1.85)	46-50 (49)	20.2-22.4 (20.7)	2.18-2.31 (2.30)	86-101 (98)	37.8-43.9 (42.0)
Non-dominant	1.76-1.98 (1.77)	35-38 (38)	15.2-16.5 (15.8)	1.46-1.81 (1.65)	44-56 (52)	19.1-23.4 (22.6)	2.19-2.22 (2.20)	100-119 (107)	43.4-49.8 (46.5)
BA3									
Dominant	2.27-2.67 (2.48)	17-21 (19)	9.5-11.0 (9.5)	1.50-2.17 (1.73)	30-37 (30)	15.0-19.4 (16.6)	2.70-3.03 (2.89)	76-83 (78)	41.0-42.0 (41.5)
Non-dominant	2.48-2.85 (2.63)	20-27 (23)	9.1-12.9 (10.7)	1.52-2.01 (1.92)	39-41 (40)	18.2-20.3 (18.6)	2.59-2.83 (2.81)	70-87 (86)	33.5-42.0 (39.7)

Table 4.10 continued

Subject	Maximum Deceleration	Maximum Unloading	Maximum Acceleration
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Table 4.10 continued

Subject Leg	Maximum Deceleration			Maximum Unloading			Maximum Acceleration		
	Times BW	Time (ms)	Percent Stance	Times BW	Time (ms)	Percent Stance	Times BW	Time (ms)	Percent Stance
S1									
Dominant	2.19-2.76 (2.37)	19-20 (19)	8.8-9.3 (9.1)	1.25-1.50 (1.43)	36-42 (39)	17.5-18.8 (18.6)	2.81-3.00 (2.83)	91-98 (95)	43.5-45.5 (44.4)
Non-dominant	3.10-3.63 (3.48)	15-25 (20)	7.0-11.0 (9.3)	1.33-1.85 (1.62)	31-38 (33)	14.5-16.5 (15.4)	2.51-2.93 (2.73)	78-98 (88)	36.5-46.0 (38.0)
S2									
Dominant	2.04-2.67 (2.14)	23-41 (34)	10.8-21.1 (19.1)	1.95-2.36 (2.02)	28-48 (44)	13.2-24.7 (24.7)	2.49-2.64 (2.61)	67-88 (84)	37.6-45.4 (39.6)
Non-dominant	1.53-2.11 (1.98)	34-45 (42)	14.7-22.0 (20.4)	1.49-2.04 (1.92)	38-49 (47)	16.0-24.0 (22.8)	2.53-2.73 (2.63)	92-106 (96)	45.0-46.6 (45.9)
SC1									
Dominant	2.44-2.90 (2.63)	15-19 (16)	6.7-8.3 (7.3)	1.25-1.51 (1.27)	34-40 (38)	15.0-18.3 (17.0)	2.42-2.77 (2.59)	97 (97)	42.5-44.3 (43.5)
Non-dominant	2.28-3.17 (3.16)	18-20 (20)	8.1-9.1 (8.8)	1.26-1.41 (1.31)	35-36 (35)	15.5-16.5 (15.7)	2.47-2.85 (2.61)	94-97 (95)	42.0-43.7 (42.9)
SC2									
Dominant	1.84-2.09 (1.84)	25-27 (26)	11.0-12.5 (12.3)	1.80-1.81 (1.81)	30 (30)	13.5-14.7 (13.8)	2.48-2.58 (2.57)	89-92 (89)	40.0-45.0 (42.0)
Non-Dominant	0.85-2.16 (2.15)	20-44 (23)	9.0-19.0 (9.7)	0.80-2.11 (1.81)	25-45 (36)	10.6-19.6 (16.2)	2.48-2.57 (2.54)	86-108 (99)	37.5-45.8 (44.6)

Table 4.10 is continued

Maximum Deceleration	Maximum Unloading	Maximum Acceleration
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Table 4.10 is continued

Subject Leg	Maximum Deceleration			Maximum Unloading			Maximum Acceleration		
	Times BW	Time (ms)	Percent Stance	Times BW	Time (ms)	Percent Stance	Times BW	Time (ms)	Percent Stance
SB1									
Dominant	2.60-3.09 (2.79)	15-17 (16)	6.1-7.2 (6.8)	1.39-1.83 (1.54)	43-44 (44)	17.6-19.9 (17.6)	2.58-2.78 (2.60)	70-77 (73)	28.0-34.8 (29.9)
Non-									
dominant	1.63-2.47 (2.15)	19-23 (22)	7.6-9.8 (9.0)	1.12-1.52 (1.20)	43-46 (44)	18.1-18.5 (18.4)	2.31-2.66 (2.44)	73-117 (74)	29.3-50.0 (30.4)
SB2									
Dominant	1.52-1.97 (1.81)	28-33 (28)	11.5-13.5 (11.5)	1.40-1.76 (1.63)	40-48 (44)	16.3-19.9 (18.0)	2.38-2.43 (2.38)	99-112 (108)	41.0-45.7 (44.3)
Non-									
dominant	1.69-2.04 (1.89)	35-39 (37)	13.8-15.2 (14.7)	1.50-1.65 (1.50)	49-52 (50)	19.3-20.2 (20.0)	2.33-2.54 (2.39)	113-117 (116)	45.0-45.8 (45.5)

* =Values in parentheses indicate the median.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB =Recreational runner who is Sighted, running with the use of the guide cable Blindfolded.

BW=Body Weight

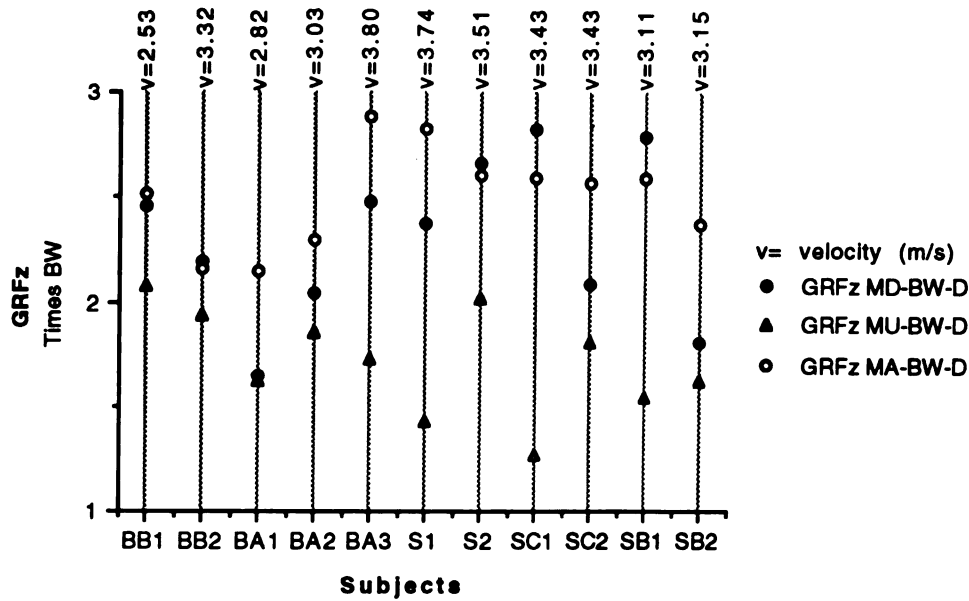


Figure 4.7

Median values in units of the subject's Body Weight (BW) for the Vertical Ground Reaction Force (GRFz) at Max-Deceleration (MD), Max-Unloading (MU), and Max-Acceleration (MA) of the Dominant leg (D) during running at own velocity ($v=m/s$). (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

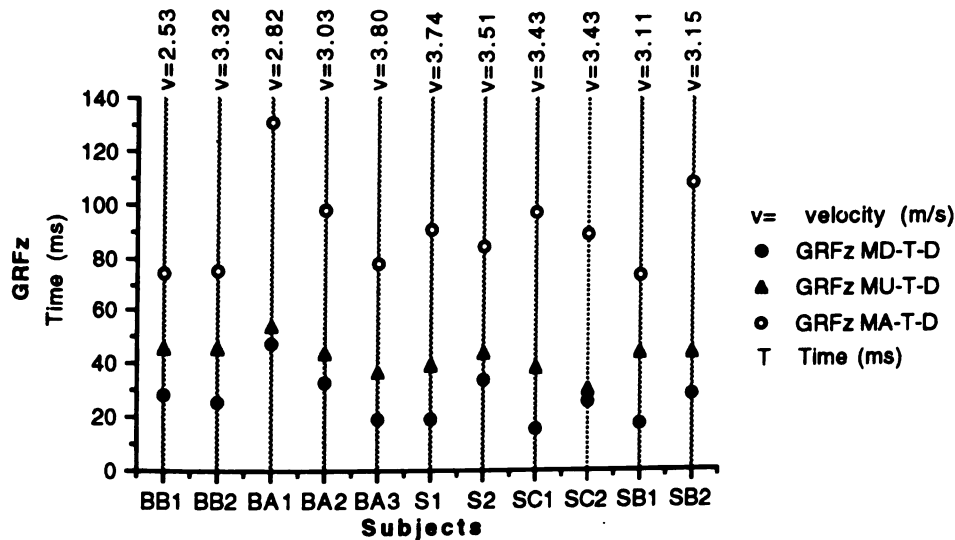


Figure 4.8

Median values of Times (ms) for the occurrence of Max-Deceleration (MD), Max-Unloading (MU), and Max-Acceleration (MA) of the Vertical Ground Reaction Force (GRFz) during the Stance Phase of the Dominant leg (D) while running at own velocity ($v=m/s$). (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

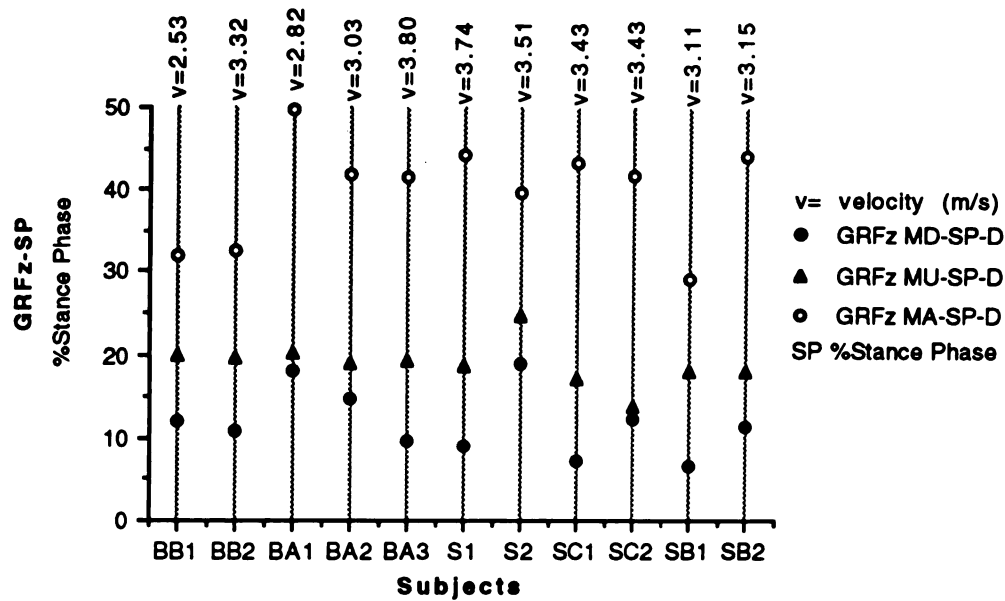


Figure 4.9

Median values of Percent Stance Phase (SP) that Max-Deceleration (MD), Max-Unloading (MU), and Max-Acceleration (MA) of the Vertical Ground Reaction Force (GRFz) occurred for the Dominant leg (D) during running at own velocity ($v=m/s$). (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

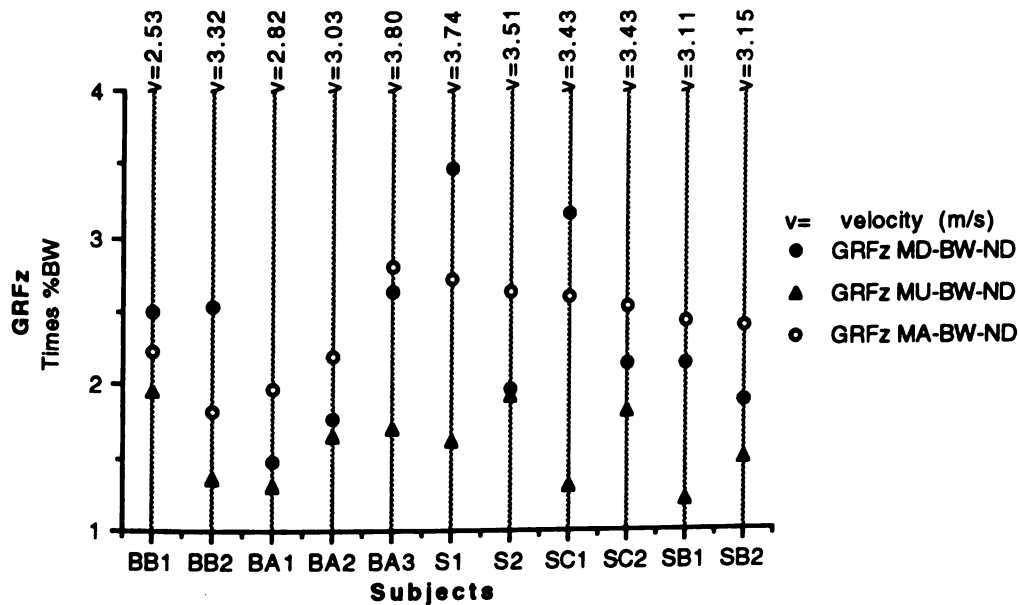


Figure 4.10

Median values in units of the subject's Body Weight (BW) for the Vertical Ground Reaction Force (GRFz) at Max-Deceleration (MD), Max-Unloading (MU), and Max-Acceleration (MA) of the Nondominant leg (ND) during running at own velocity ($v=m/s$). (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

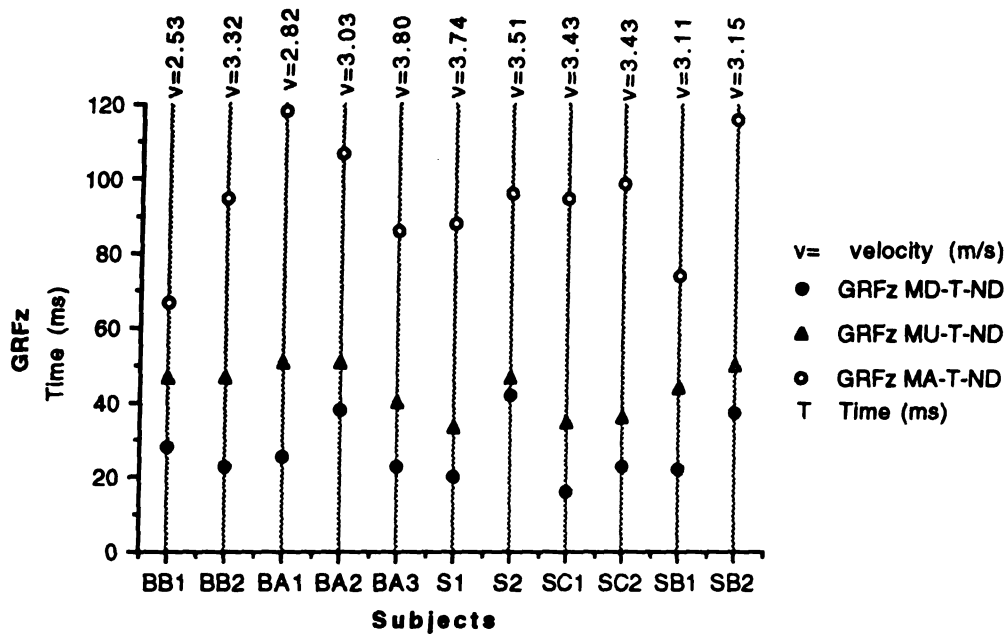


Figure 4.11

Median values of Times (ms) for the occurrence of Max-Deceleration (MD), Max-Unloading (MU), and Max-Acceleration (MA) of the Vertical Ground Reaction Force (GRFz) during the Stance Phase of the Nondominant leg (ND) while running at own velocity (v=m/s). (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

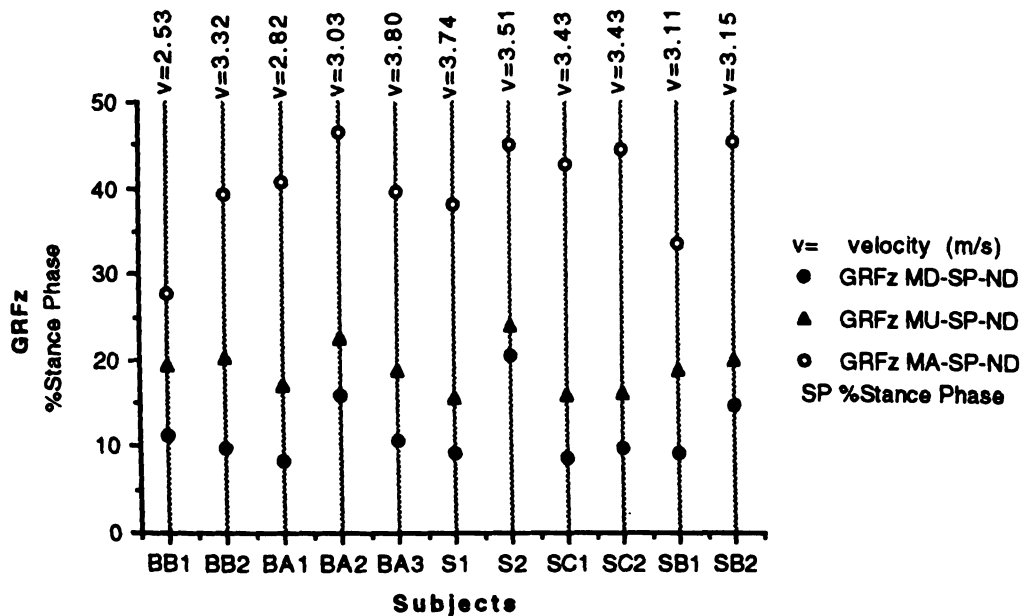


Figure 4.12

Median values of Percent Stance Phase (SP) that Max-Deceleration (MD), Max-Unloading (MU), and Max-Acceleration (MA) of the Vertical Ground Reaction Force (GRFz) occurred for the Dominant leg (D) during running at own velocity (v=m/s). (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

decelerating forces, in times BW, in most trials compared to the BA1 and BA2 subjects (see Table 4.10). Only subject BA3 whose running velocity was faster demonstrated occurrence of maximum deceleration for most trials of the dominant and nondominant supporting leg earlier in time and in percent stance phase compared to the other subjects who were blind (see Table 4.10).

All the subjects in the BA subgroup had lower median values for maximum unloading than subjects in the BB subgroup for the dominant leg (see Figure 4.7). In fact, in most cases all the subjects in the BA subgroup experienced lower maximum unloading forces in the dominant leg than the forces that the subjects in the BB subgroup experienced in the same leg (see Table 4.10). The difference in time from maximum deceleration medians to maximum unloading medians of the dominant leg was greater for the individual performances of all the subjects in the BB subgroup than for the subjects in the BA subgroup (Figure 4.8). The maximum unloading in most trials also occurred earlier for the subjects in the BB subgroup for the dominant and the nondominant legs (see Table 4.10). An exception to this was subject BA3 who ran faster than the other subjects who were blind. In terms of percent of stance phase, maximum unloading for all subjects except BA1 for the nondominant leg and BA3 for both the dominant and nondominant legs, occurred at the same time, at approximately 20 percent of the stance phase (see Table 4.10).

Maximum acceleration loading, in times BW, was the highest for BB1 and BA3 among all the subjects despite the fact that BB1 was performing with the slowest velocity. The maximum acceleration also occurred earlier for the subjects in the BB subgroup for both dominant

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and nondominant legs (see Table 4.10). In only one trial of subject BB2 maximum acceleration occurred later for his dominant leg compared to subject BA2's dominant leg. Also, in only one trial of subject BA1's nondominant leg maximum acceleration occurred earlier than some trials of the subjects in the BB subgroup (see Table 4.10).

The sighted subjects under the S condition demonstrated variability for the peak decelerating forces they experienced in both dominant and nondominant legs. When the sighted subjects performed under the SC and SB conditions, no consistent pattern could be observed other than that the maximum deceleration occurred at relatively the same times for each subject for both running conditions for the dominant leg. However, under the SC and SB conditions, they demonstrated the highest intra-subject consistency for maximum unloading and maximum acceleration. The nondominant leg demonstrated more variability.

Rate of Loading

In addition to the vertical component of the ground reaction, the rate of loading was studied for each subject and each classification (see Table 4.11). The subjects in the BB subgroup experienced higher rates of loading than the subjects in the BA subgroups, BA1 and BA2, who were running at comparable velocities. Subjects S1 and SC2 experienced the highest rate of loading of all subjects for both legs, whereas subject S2's rates of loading were similar to BA1, and BA2. Under the SB condition, only subject SB2's rates of loading appeared to be comparable to BA1, and BA2 who ran at similar velocities (see Table 4.11).

Table 4.11

Loading rate of the dominant and nondominant leg during foot strike (three trials for each leg).

Subjects Leg	Velocity (m/s)	Loading Rate (BW.ms ⁻¹ *100)
BB1	2.41 - 3.80	
Dominant		81.5 - 91.2 (84.1)*
Nondominant		69.0 - 100.2 (72.3)
BB2	3.32 - 3.60	
Dominant		78.3 - 148.7 (82.4)
Nondominant		64.3 - 120.0 (115.8)
BA1	2.77 - 2.95	
Dominant		32.4 - 41.9 (33.6)
Nondominant		55.8 - 77.6 (59.3)
BA2	2.78 - 3.65	
Dominant		46.3 - 52.0 (50.8)
Nondominant		52.0 - 75.3 (62.0)
BA3	3.05 - 3.91	
Dominant		105.6 - 131.5 (130.5)
Nondominant		127.4 - 133.7 (128.1)
S1	3.52 - 3.81	
Dominant		115.4 - 145.4 (118.5)
Nondominant		145.2 - 232.0 (155.0)
S2	3.42 - 3.60	
Dominant		52.1 - 88.6 (78.7)
Nondominant		44.9 - 47.3 (46.8)

Table 4.11 continued

Subjects Leg	Velocity (m/s)	Loading Rate (BW.ms ⁻¹ *100)
SC1	3.39 - 3.72	
Dominant		148.9 - 193.3 (152.5)
Nondominant		126.6 - 158.5 (158.0)
SC2	3.36 - 3.53	
Dominant		70.9 - 77.6 (73.6)
Nondominant		37.1 - 107.9 (49.2)
SB1	3.04 - 3.29	
Dominant		71.1 - 130.0 (97.8)
Nondominant		162.5 - 206.0 (164.0)
SB2	2.99 - 3.24	
Dominant		53.9 - 70.3 (54.8)
Nondominant		43.3 - 55.1 (53.7)

* = Median values are in parentheses.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

BW = Body Weight.

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Anterior-posterior Ground Reaction Force

The performance of each subject's dominant and nondominant leg on selected parameters of the anterior-posterior component of the ground reaction force was studied and the results, expressed in ranges and medians, are presented in Table 4.12. A graphical representation of the medians is presented in Figures 4.13 to 4.18.

In the BB subgroup, subject BB1, a forefoot striker, had a double peak braking force. Subject BB2 who was a rearfoot striker, had also a slight tendency for a double peak. The maximum brake peak values varied between subjects in terms of magnitude and in terms of when they occurred. It was noticed, however, that the second maximum peak for both the dominant and the nondominant legs, occurred in most trials between 20 and 24 percent of the stance phase. For subject BB1 the transition from brake to propulsion occurred at 43 to 46.8 percent of the stance phase for the dominant leg, and at 32.5 to 41 percent of the stance phase for the nondominant leg. For subject BB2 the transition from brake to propulsion occurred at 44 to 60 percent of the stance phase and 43.5 to 51 percent stance phase for the dominant and nondominant leg, respectively. Maximum propulsion occurred for both subjects at 70 to 75 percent of the stance phase for both the dominant and the nondominant leg and it ranged from 0.24 to 0.34 BW.

In the BA subgroup, subject BA1 had a double peak brake only on the dominant leg. Subject BA3 also had a pronounced tendency for a double peak brake, but on the nondominant leg. Subject BA2 demonstrated double peak brakes on both legs. Maximum peak brake values varied according to first or second peak. For the nondominant leg, maximum

Performance of the dominant and nondominant leg on selected parameters of the anterior-posterior component of the ground reaction force
 (three trials for each leg)

Maximum Peak	Minimum Peak	Minimum Peak	Minimum Peak
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Table 4.12
Performance of the dominant and nondominant leg on selected parameters of the anterior-posterior component of the ground reaction force (three trials for each leg).

Subject Leg	Maximum Brake			Transition		Maximum Propulsion		
	Times BW	Time (ms)	Percent Stance	Time (ms)	Percent Stance	Times BW	Time (ms)	Percent Stance
BB1								
Dominant	0.22-0.36 (0.30)* 0.23-0.38 (0.32)	18-22 (20) 47-52 (49)	7.7-9.0 (8.6) 20.0-22.3 (20.3)	100-109 (107)	43.1-46.8 (43.7)	0.23-0.26 (0.23)	170-180 (177)	71.0-75.5 (75.4)
Non- dominant	0.20-0.35 (0.33) 0.19-0.24 (0.19)	18-21 (19) 51-55 (52)	7.2-8.7 (7.8) 20.0-23.0 (21.4)	81-92 (85)	32.5-41.0 (35.0)	0.24-0.27 (0.26)	170-188 (177)	70.5-75.5 (72.8)
BB2								
Dominant	0.22-0.83 (0.63) 0.44-0.56 (0.48)	15-38 (31) 36-56 (53)	6.3-16.1 (13.5) 15.0-24.0 (23.0)	105-142 (110)	44.0-60.0 (47.8)	0.25-0.35 (0.26)	161-187 (183)	70.0-78.2 (77.5)
Non- dominant	0.12-0.65 (0.36) 0.30-0.41 (0.37)	17-41 (32) 32-61 (56)	7.5-15.0 (13.7) 14.0-24.0 (23.6)	100-119 (113)	43.5-51.1 (43.7)	0.30-0.34 (0.32)	176-182 (181)	70.2-77.7 (77.1)

Table 4.12 continued

Subject	Maximum Brake		Transition		Maximum Propulsion	
	Times BW	Time (ms)	Percent	Time (ms)	Times BW	Time (ms)

Table 4.12 continued

Subject Leg	Maximum Brake			Transition		Maximum Propulsion		
	Times BW	Time (ms)	Percent Stance	Time (ms)	Percent Stance	Times BW	Time (ms)	Percent Stance
BA1								
Dominant	0.35-0.39 (0.38)	19-24 (21)	7.0-8.7 (8.5)	128-137 (133)	47.2-54.9 (48.4)	0.37-0.41 (0.41)	196-204 (203)	74.2-81.0 (74.9)
Non- dominant	0.35-0.41 (0.38)	53-57 (57)	20.1-21.9 (21.0)					
BA2								
Dominant	0.39-0.56 (0.44)	48-69 (69)	16.4-23.8 (23.1)	155-162 (158)	52.0-55.5 (54.7)	0.29-0.31 (0.29)	213-226 (223)	73.7-75.7 (74.8)
Non- dominant	0.23-0.35 (0.32)	16-17 (17)	7.0-7.6 (7.2)	103-108 (107)	45.3-47.5 (46.2)	0.41-0.43 (0.42)	157-164 (162)	69.1-72.6 (71.6)
BA3								
Dominant	0.18-0.24 (0.19)	58-60 (59)	25.4-26.4 (25.5)					
Non- dominant	0.33-0.51 (0.43)	15-19 (17)	6.5-7.9 (7.4)	98-113 (102)	42.6-47.3 (44.3)	0.36-0.39 (0.39)	165-180 (169)	71.7-75.3 (73.5)
BA3								
Dominant	0.28-0.40 (0.32)	59-68 (67)	22.6-29.5 (28.0)					
Non- dominant	0.25-0.33 (0.30)	46-54 (52)	25.5-27.2 (27.0)	72-97 (96)	40.0-50.8 (48.0)	0.33-0.46 (0.38)	134-149 (144)	72.2-74.5 (74.4)
BA3								
Dominant	0.37-0.57 (0.40)	35-39 (38)	16.7-19.3 (17.3)	109-112 (112)	51.1-54.4 (52.2)	0.28-0.37 (0.36)	146-155 (153)	69.4-72.2 (71.5)
Non- dominant	0.43-0.59 (0.58)	51-55 (54)	24.4-27.2 (24.7)					

Table 4.12 continued

Subject	Maximum Brake		Transition		Maximum Propulsion	
	Times BW	Time (ms)	Percent	Time (ms)	Times BW	Time (ms)

Table 4.12 continued

Subject Leg	Maximum Brake			Transition		Maximum Propulsion		
	Times BW	Time (ms)	Percent Stance	Time (ms)	Percent Stance	Times BW	Time (ms)	Percent Stance
S1								
Dominant	0.41-0.46 (0.42)	53-57 (54)	20.0-25.8 (25.2)	97-108 (99)	47.3-48.2 (47.6)	0.36-0.61 (0.55)	151-171 (160)	66.8-83.4 (74.0)
Non- dominant	0.33-0.60 (0.47)	43-49 (46)	20.2-21.6 (21.2)	87-122 (87)	40.8-52.8 (40.8)	0.46-0.49 (0.47)	156-175 (162)	67.5-82.2 (76.0)
S2								
Dominant	0.21-0.41 (0.31) 0.19-0.36 (0.24)	12-25 (19) 48-53 (52)	6.7-11.8 (9.8) 24.7-29.2 (25.0)	68-101 (83)	38.0-47.6 (42.78)	0.39-0.51 (0.46)	120-150 (140)	67.5-72.1 (70.8)
Non- dominant	0.13-0.22 (0.19) 0.28-0.40 (0.34)	19-27 (20) 47-62 (48)	9.3-11.3 (9.7) 22.8-26.0 (23.5)	93-114 (93)	45.0-48.0 (45.5)	0.35-0.44 (0.43)	143-165 (151)	69.3-73.3 (72.1)
SC1								
Dominant	0.37-0.41 (0.39)	43-53 (48)	19.6-23.7 (21.0)	103-106 (103)	45.4-47.7 (47.0)	0.43-0.47 (0.45)	164-170 (164)	71.6-75.8 (74.0)
Non- dominant	0.50-0.51 (0.50)	48-50 (48)	21.6-22.0 (21.9)	97-113 (99)	44.3-49.0 (44.4)	0.39-0.51 (0.44)	166-175 (170)	74.9-78.8 (75.8)
SC2								
Dominant	0.17 (0.17) 0.23-0.34 (0.34)	20 (20) 50-55 (50)	9.0-9.8 (9.2) 24.5-24.6 (24.5)	87-107 (89)	42.6-48.0 (44.8)	0.38-0.43 (0.39)	139-162 (143)	68.1-75.3 (73.2)
Non- dominant	0.31-0.36 (0.33)	49-67 (56)	21.4-28.4 (25.2)	97-108 (103)	42.4-46.4 (45.8)	0.36-0.40 (0.40)	147-164 (162)	64.2-73.0 (69.5)

Table 4.12 continued

Subject	Maximum Brake		Transition		Maximum Propulsion	
	Times BW	Time (ms)	Percent	Time (ms)	Times BW	Time (ms)
			Percent			Percent

Table 4.12 continued

Subject Leg	Maximum Brake			Transition		Maximum Propulsion		
	Times BW	Time (ms)	Percent Stance	Time (ms)	Percent Stance	Times BW	Time (ms)	Percent Stance
SB1								
Dominant	0.31-0.59 (0.45)	46-60 (58)	20.8-24.6 (23.2)	109-139 (116)	46.4-56.9 (49.3)	0.30-0.49 (0.34)	162-194 (188)	73.3-79.5 (75.2)
Non- dominant	0.64-0.93 (0.70)	40-41 (40)	16.0-17.0 (16.9)	136-143 (143)	54.6-61.1 (58.8)	0.27-0.28 (0.26)	188-191 (189)	75.9-80.3 (78.6)
SB2								
Dominant	0.25-0.29 (0.28)	60-63 (61)	24.5-26.0 (25.0)	115-123 (119)	47.0-50.5 (49.4)	0.26-0.32 (0.28)	178-184 (181)	70.5-73.0 (71.0)
Non- dominant	0.43-0.49 (0.49)	62-63 (62)	24.1-25.0 (24.9)	130-133 (133)	51.0-53.2 (53.0)	0.25-0.28 (0.27)	182-188 (188)	72.0-75.0 (74.9)

* = Values in parentheses indicate the median.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

BW = Body Weight.

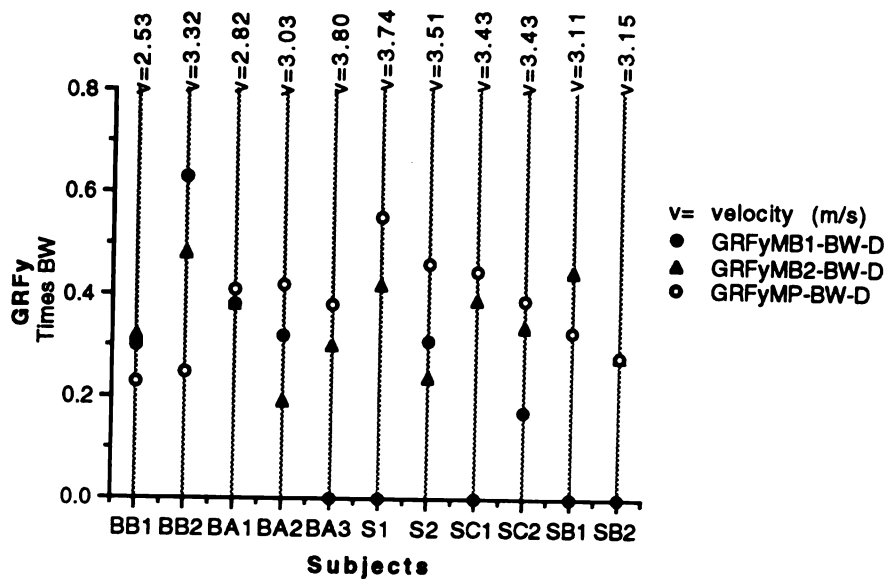


Figure 4.13

Median values in units of the subject's Body Weight (BW) for the Antero-posterior Ground Reaction Force (GRFy) at First Max-Brake (MB1), Second Max-Brake (MB2), and Max-Propulsion (MP) of the Dominant leg (D) during running at own velocity ($v=m/s$). (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

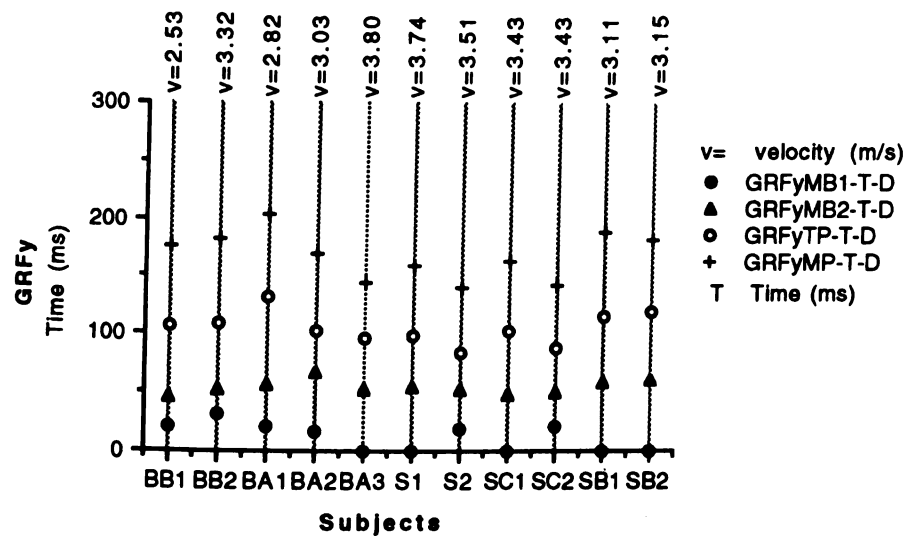


Figure 4.14

Median values of Times (ms) for the occurrence of First Max-Brake (MB1), Second Max-Brake (MB2), Transition to Propulsion (TP), and Max-Propulsion (MP) of the Antero-posterior Ground Reaction Force (GRFy) during the Stance Phase of the Dominant leg (D) while running at own velocity ($v=m/s$). (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

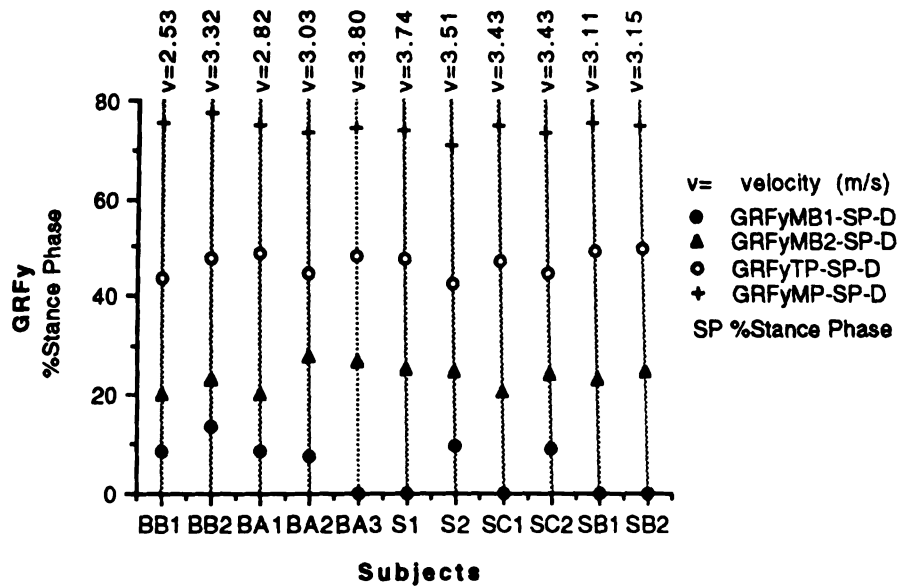


Figure 4.15

Median values of Percent Stance Phase (SP) that First Max-Brake (MB1), Second Max-Brake (MB2), Transition to Propulsion (TP), and Max-Propulsion (MP) of the Antero-posterior Ground Reaction Force (GRFy) occurred for the Dominant leg (D) during running at own velocity (v =m/s). (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

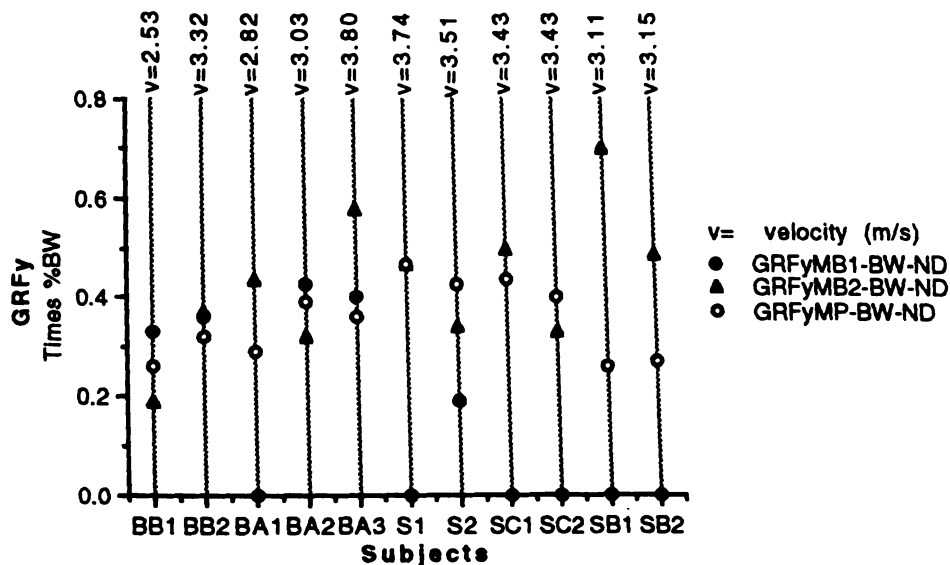


Figure 4.16

Median values in units of the subject's Body Weight (BW) for the Antero-posterior Ground Reaction Force (GRFy) at First Max-Brake (MB1), Second Max-Brake (MB2), and Max-Propulsion (MP) of the Nondominant leg (ND) during running at own velocity (v =m/s). (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

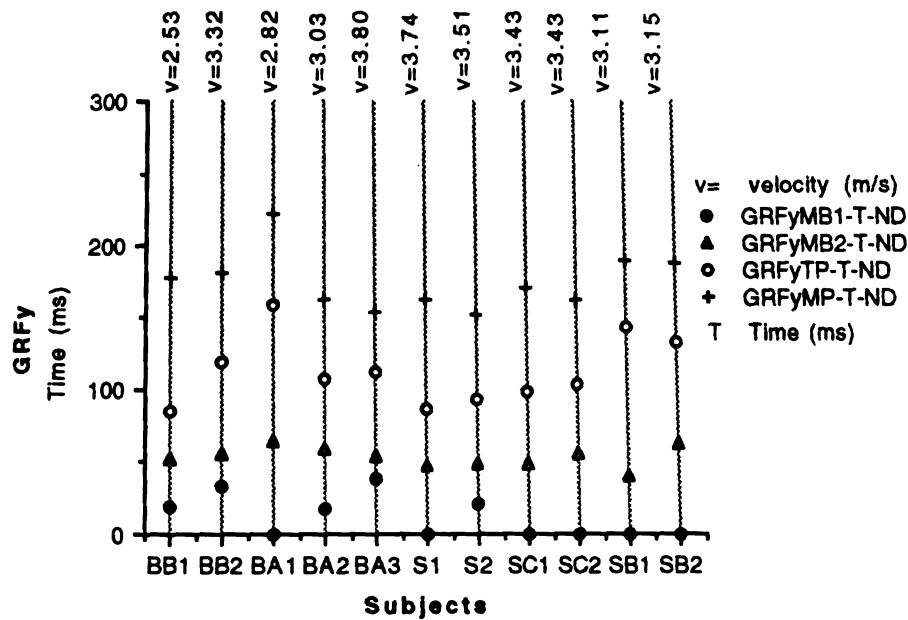


Figure 4.17

Median values of Times (ms) for the occurrence of First Max-Brake (MB1), Second Max-Brake (MB2), Transition to Propulsion (TP), and Max-Propulsion (MP) of the Antero-posterior Ground Reaction Force (GRFy) during the Stance Phase of the Nondominant leg (ND) while running at own velocity (v=m/s). (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

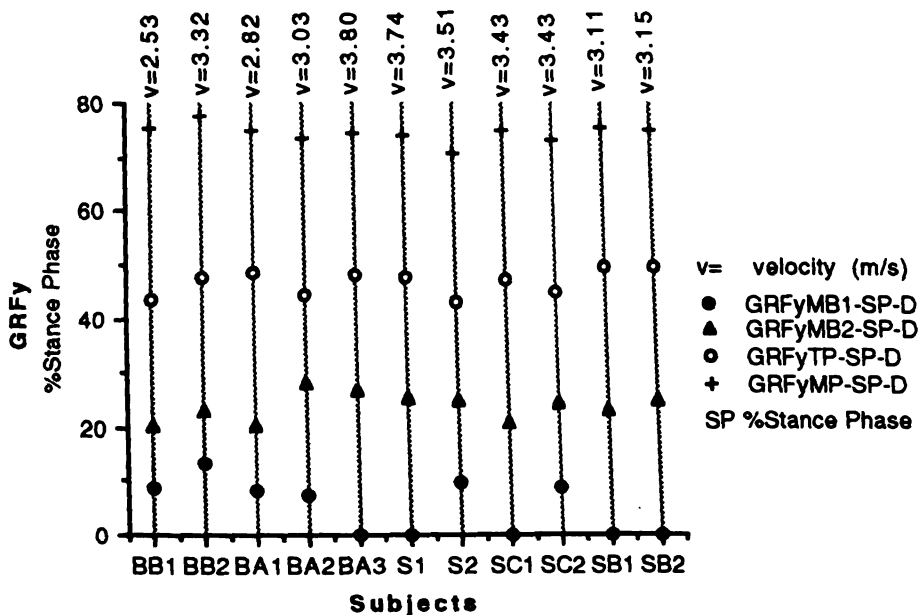


Figure 4.18

Median values of Percent Stance Phase (SP) that First Max-Brake (MB1), Second Max-Brake (MB2), Transition to Propulsion (TP), and Max-Propulsion (MP) of the Antero-posterior Ground Reaction Force (GRFy) occurred for the Nondominant leg (ND) during running at own velocity (v=m/s). (BB=Blind Before five years of age, BA=Blind After five years of age, S=Sighted using vision, SC= Sighted using vision and guide Cable, SB= Sighted but Blindfolded using guide cable).

brake peak values ranged from 0.28 to 0.59 BW, and for the dominant leg from 0.18 to 0.41 BW. In most cases there was intra-subject consistency in terms of percent of the stance phase when events during the braking and transition phases occurred. For example, maximum brake for subject BA3 occurred between 25.5 and 27.2 percent of the stance phase, and 24.4 to 27.7 percent of the stance phase for the dominant and nondominant leg, respectively. For subject BA2 transition occurred from 42.6 to 47.2 percent of the stance phase and from 45.3 to 47.5 percent of the stance phase for the dominant and nondominant leg, respectively. Transition, in general, occurred faster in the dominant leg (see Table 4.12). Peak propulsion values for the subjects in the BA subgroup ranged from 0.28 to 0.46 BW, and they occurred from 69.1 to 80.9 percent of the stance phase for both the dominant and the nondominant leg (see Table 4.12).

Subject S2 demonstrated a double braking peak, whereas subject S1 demonstrated only one. The kinetic results in the performance of the selected parameters of the anterior-posterior component of the ground reaction force for the subjects running under the S, SC, and SB running conditions are represented in Table 4.12. There was intra-subject consistency in the forces experienced by the sighted subjects under the S and SC running conditions. However, in general, the ranges within which the events of the stance phase occurred and the ranges of the loading forces that were experienced, were narrower when the subjects ran with the use of the guide cable. When the subjects ran under the SB running condition, the braking force experienced increased and the relative time from peak brake to transition, and from transition to peak

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propulsion increased in all trials but one (see Table 4.12, and Figures 4.14 and 4.17).

Medio-lateral ground reaction force

The loading ranges for the performance of every subject subgroup in terms of the medio-lateral forces experienced during the stance phase in running, are presented in Table 4.13. The medio-lateral component of the ground reaction force had a great intra-subject and inter-subject variability in the occurrence of peak values and in the kind of forces, medial or lateral, that occurred. For example, BB2 started at foot strike with his nondominant leg laterally, progressed medially, and most of the time ended laterally at toe-off. His dominant leg most times started at foot strike medially, progressed laterally, medially, laterally, and ended medially at toe-off. Peak-to-peak values for the subjects in the BB subgroup ranged medially from 0.10 to 0.23 BW, and laterally from 0.01 to 0.21 BW (see Table 4.13). Most of the BA subjects started laterally. Peak-to-peak values ranged medially from 0.03 to 0.24 BW and laterally from 0.09 to 0.26 BW (see Table 4.13). Most times the sighted subjects started laterally and progressed medially. Medial values ranged from 0.1 to 0.5 BW medially and from 0.06 to 0.3 BW laterally (see Table 4.13). Subjects in the SC subgroup most times started laterally. Medial values ranged from 0.13 to 0.34 BW and from 0.03 to 0.17 BW for the lateral values (see Table 4.13). Subjects in the SB subgroup had started most trials laterally. Peak-to-peak values ranged laterally from 0.03 to 0.26 BW and from 0.03 to 0.2 BW medially.

Table 4.13

Range of the medio-lateral component of the ground reaction force for each subject classification, expressed proportionally to the subject's body weight (six trials).

Subjects	Medial Times BW	Lateral Times BW
BB	0.10 - 0.23	0.01 - 0.21
BA	0.03 - 0.24	0.09 - 0.26
S	0.10 - 0.50	0.06 - 0.30
SC	0.13 - 0.34	0.03 - 0.17
SB	0.03 - 0.20	0.03 - 0.26

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

BW= Body Weight

Braking and Propulsive Impulse

In addition to the anterior-posterior component of the ground reaction, the propulsive and braking impulses were calculated for each trial in order to verify that the subjects performed at a constant speed. (A constant speed has been achieved when the braking impulse is similar or equal to the propulsive impulse.) A summary of the results is presented in Table 4.14. The impulses were different for the dominant and nondominant legs. For all the trials of the BB subjects, the propulsive impulse of the nondominant leg was greater than its braking impulse. In contrast, the braking impulse of the dominant leg was always greater than its propulsive impulse. The opposite was true for the BA subjects. The propulsive impulse was always larger for the S subjects and SC subjects. When the sighted subjects performed under the SB running condition, the propulsive impulse of the dominant leg was greater than its braking impulse. Under the same condition, the braking impulse of the nondominant leg was greater than its propulsive impulse.

Discussion

Before the investigator engages to any kind of discussion about the results of the study as they pertain to the hypotheses, it is felt necessary to state that the results presented were influenced, and to an extent determined, by three main factors: (a) the limited runway, (b) the testing speed, and (c) the laboratory facility as a whole.

The propulsive impulses of the subjects running under the S and SC running conditions were a lot higher than the braking impulses of the corresponding legs (see Table 4.14). Therefore, as the kinematic data also suggested, the subjects running under the S and SC conditions,

Table 4.14

Ranges of impulses from the anterior-posterior force during the stance phase for the dominant and nondominant leg of each subject for three trials for each leg.

Subjects Leg	Braking Impulse (Ns)	Propulsive Impulse (Ns)
BB1		
Dominant	12.55 - 21.21 (18.33)*	9.68 - 17.01 (9.69)
Nondominant	7.53 - 17.67 (15.53)	17.84 - 20.47 (17.84)
BB2		
Dominant	14.32 - 16.06 (14.79)	9.35 - 12.72 (9.99)
Nondominant	9.65 - 18.76 (10.49)	17.82 - 24.90 (18.39)
BA1		
Dominant	24.90 - 31.49 (27.76)	29.70 - 36.40 (33.65)
Nondominant	33.63 - 46.15 (35.93)	10.79 - 25.76 (22.43)
BA2		
Dominant	16.41 - 21.92 (17.85)	24.65 - 25.57 (25.05)
Nondominant	15.23 - 20.78 (15.31)	9.21 - 14.4 (10.16)
BA3		
Dominant	3.62 - 8.57 (8.41)	13.10 - 19.25 (14.83)
Nondominant	15.98 - 20.35 (19.24)	9.30 - 12.90 (11.01)
S1		
Dominant	9.17 - 23.25 (9.18)	14.76 - 28.56 (22.49)
Nondominant	9.86 - 13.08 (10.50)	17.14 - 19.85 (18.94)
S2		
Dominant	6.57 - 13.83 (9.26)	17.49 - 24.19 (22.38)
Nondominant	10.12 - 18.10 (11.89)	19.57 - 22.56 (21.52)

Table 4.14 continued

Subjects Leg	Braking Impulse (Ns)	Propulsive Impulse (Ns)
SC1		
Dominant	9.64 - 14.11 (11.36)	17.63 - 23.36 (18.83)
Nondominant	13.92 - 14.84 (14.39)	17.73 - 21.51 (19.95)
SC2		
Dominant	11.76 - 16.13 (13.83)	18.89 - 21.83 (19.75)
Nondominant	7.62 - 14.75 (13.38)	17.86 - 21.56 (21.37)
SB1		
Dominant	11.34 - 24.31 (12.08)	10.74 - 26.34 (15.46)
Nondominant	28.04 - 35.68 (33.10)	9.12 - 11.52 (9.83)
SB2		
Dominant	7.170 - 12.39 (10.78)	13.91 - 18.16 (14.44)
Nondominant	22.59 - 27.17 (23.88)	13.04 - 17.04 (15.45)

* = Median values are in parentheses.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

although they had achieved the testing velocity, were still undergoing acceleration when they entered the filming area and stepped on the force platform (see Figure 4.19 and Figure 4.20). The reason that the subjects in the S and SC subgroups were still undergoing acceleration when they were in the filming area, which included the force plate, may be that the distance between the starting point and the filming area was not adequate for them to reach a steady pace at the desired velocity for the study. As a result, the numerical data obtained for the subjects in the S and SC subgroups are not valid for individuals running at constant speed. They are valid for individuals who accelerate. However, although the results for the sighted subjects cannot be used for accurate numerical conclusions, because the subjects had reached the testing velocity and they were about to reach a steady pace, the results can be used for general comparisons and discussion of Hypothesis 7. Consequently, the discussion of the hypotheses related to the sighted subjects will be integrated, whenever possible, with the Hypotheses 4 and 6.

Specifically, Hypothesis 3 and the part of Hypothesis 8 relevant to kinematics, will be discussed together with Hypothesis 4. Hypotheses 5 and 8, the part relevant to the kinetics, will be discussed together with Hypothesis 6 (see Chapters I or II for the content of these hypotheses).

The testing speed varied across subjects (see Table 4.1). During the warm up the subjects ran on the treadmill at the desired testing velocity and the metronome was set at their individual pace for that speed. However, when they ran on the runway, the subjects used the metronome as a reference in order to perform at their own natural speed. The natural speed of the recreational runners who were blind, although close,

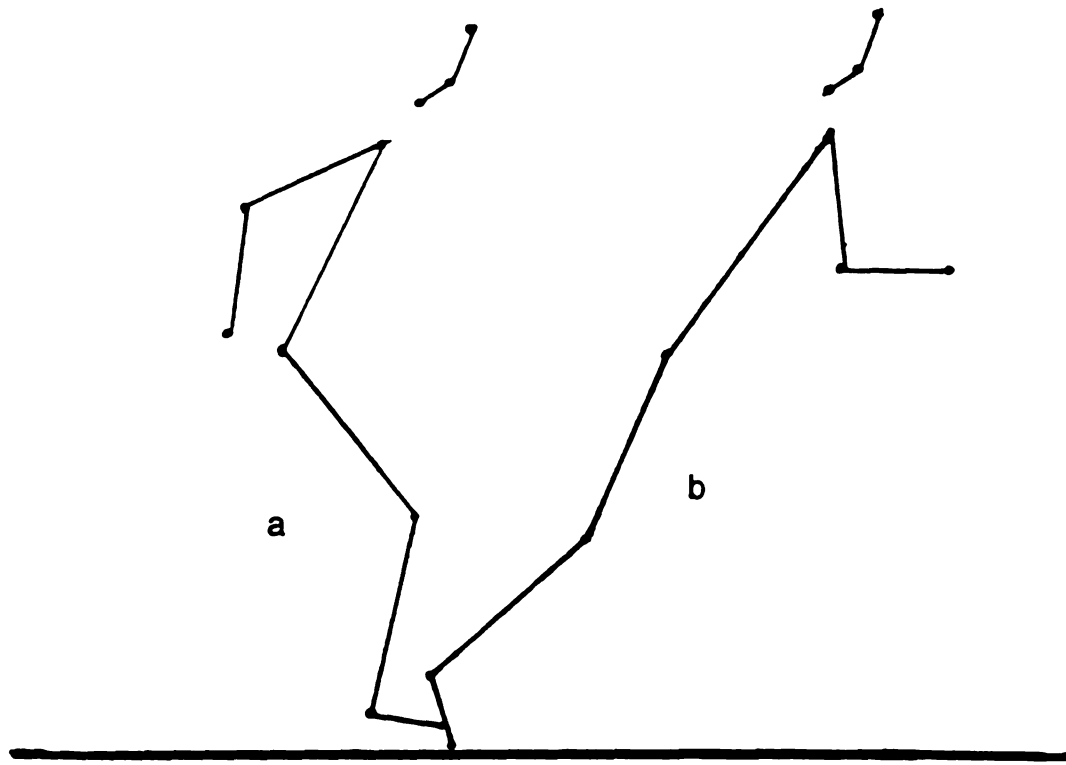


Figure 4.19
Subject S2 running: a) foot strike and b) toe-off.

most of the time was slower than the natural speed of the recreational runners who were sighted. One of the reasons, as was the case for BB1, was that he was accelerating more vertically than horizontally at the beep of the metronome. Also, the speed of the sighted runners remained the same, but in a narrower range, when they ran as SC, which suggested that the guide rope forced them to a more consistent performance, and the speed decreased when they ran under the SB condition. Therefore, it can be concluded that the decreased speed of the sighted runners is partly the result of using the assistive device, and is partly the result of being visually impaired and using inappropriate technique to run. The results are presented relative to this range of speed.

All the results of this study, in general, are specific to the laboratory facility. Therefore, whenever possible, there was effort to normalize the data to allow for comparisons with the existing literature.

Hypothesis 1

At similar velocities, B1 recreational runners will have a longer contact period with the ground during the stance phase of running than sighted subjects.

The results of this study support the hypothesis (see Figure 4.1, and Table 4.1) if it can be assumed that once a steady pace has been achieved, the stance time for the sighted runners will not change substantially, particularly since they had already reached the desired testing speed. To compare the findings of this study with what has been reported in the literature, the stance phase was expressed as a percent of cycle length (see Table 4.15 for the ranges and the medians, and Appendix R for the individual performances). Mann et al. (1986) reported

the stance phase to be 32.5 percent of the cycle length at a speed of 3.31 m/s. In this study, the stance phases, expressed in percent of the cycle length, of the recreational runners who were blind and ran at comparable speeds were 30.8-38.4 percent of the cycle length with most of them ranging from 33.6-38.4 percent of the cycle length. Only subject BA3's values were lower than those of the other subjects who were blind. However, subject BA3's running velocity in most trials was greater than the velocity of the other subjects who were blind. The higher running velocity of subject BA3 justifies the lower values he exhibited when his stance phases were expressed as percent of the cycle length. It can be observed, therefore, from Table 4.15 and Appendix R, that the stance phase of the recreational runners who were blind was longer than the stance phase reported in the literature for the sighted subjects. This finding is also supported by Gorton and Gavron (1987) who found that the greater the degree of blindness, the longer the stance phase, and by MacGowan (1985) who analyzed the walking gait of individuals who were blind.

Another finding was that the stance phases of the recreational runners who were blind had to be separated into two subdivisions, the stance phase for the dominant leg and the stance phase for the nondominant leg. The stance phase for the dominant leg was shorter and usually responsible for the highest propulsive and accelerating forces experienced whereas the stance phase for the nondominant leg was longer and usually experienced the high decelerating and breaking forces. This finding led to the definitions of the dominant and nondominant legs in the beginning of this project. This suggested asymmetries for each of the subjects who were blind. The dominant and nondominant legs were

Table 4.15

Stance phase ranges from the cinematographic data for each subject expressed in percent of cycle length for five trials.

Subjects	Velocity (m/s)	Percent Cycle Length
BB1	2.41 - 3.80 (2.53)*	34.7 - 36.4 (35.5)
BB2	3.32 - 3.60 (3.32)	36.1 - 38.4 (36.3)
BA1	2.77 - 2.95 (2.82)	36.2 - 40.2 (38.0)
BA2	2.78 - 3.65 (3.03)	33.6 - 37.2 (36.1)
BA3	3.05 - 3.91 (3.80)	30.8 - 33.9 (31.2)
S1	3.52 - 3.81 (3.74)	25.3 - 28.3 (28.0)
S2	3.42 - 3.60 (3.51)	26.3 - 30.0 (28.4)
SC1	3.39 - 3.72 (3.43)	26.2 - 31.8 (30.2)
SC2	3.36 - 3.53 (3.43)	29.0 - 32.5 (30.8)
SB1	3.04 - 3.29 (3.11)	31.8 - 41.4 (34.0)
SB2	2.99 - 3.24 (3.15)	34.0 - 34.1 (34.1)

* = Median values are in parentheses.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

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independent of the testing set up, i.e., each subject's right side on which the guide cable was positioned. However, the values might have been different had the cable been positioned on each subject's preferred side or had there been no cable. It seemed that the dominant leg effect was more an asymmetry build-up over the years inversely related to the side each subject used to hold on to the guiding means (person, dog, cane, etc.) used for ambulation. The side opposite to the one providing guidance appeared to be the dominant side. For example, BA3 used to hold his guide dog with his right hand when he trained. The left leg was his dominant leg.

Hypothesis 2

At similar velocities, B1 recreational runners will cover less distance per stride relative to their lower limb length when they run than S runners.

Stride Length

During the analysis of the data, it was noticed that, for all the trials that were filmed for the sighted subjects, the first stride was always shorter than the one following it. This suggested that their stride length increased as a function of time which, in turn, indicated that the subjects were undergoing acceleration. The results for the second stride of the sighted subjects reflect their performance better and they were comparable to the information in the literature for other sighted runners. The stride length of the subjects in the S subgroup ranged from 60 to 77 percent of standing height with shoes (%SHS) and from 133 to 156 percent of the lower limb length (%LLL). These values agreed with Roy (1982) who reported that at a speed of 3 m/s the stride length was

between 68 and 72 %SHS and about 150 %LLL. The stride length of the recreational runners who were blind probably depended on the leg dominance. The stride length following the stance phase of the dominant leg was longer. In general, the overall stride and cycle length of the recreational runners who were blind was shorter than that of the recreational runners with no visual characteristic when they ran under the S and SC running conditions. This result was in agreement with the findings of Arnhold and McGrain (1985). Consequently, the results of this study support Hypothesis 2. However, this may not be the result of the disability alone. It may be the result of using the guide cable, or a combination of both the blindness and the use of the guide cable.

Airborne Phase

In an effort to verify if the longer stance phase was the only reason why the stride length was shorter when compared to that of the sighted subjects, the airborne phase was also calculated. The recreational runners who were blind had a shorter airborne phase than the sighted subjects. As a matter of fact, with the exception of subject BA3, the subjects with no visual characteristic had longer airborne phases compared to the runners who were blind for most of the trials under all running conditions. However, when the sighted subjects ran under the SB running condition the stance phase increased and became comparable to that of the runners who were blind. The airborne phase also decreased, but it remained longer for the majority of the trials than that of the runners who were blind. The stance phase of the subjects in the SC subgroup increased when they ran with the use of the guide cable, but the airborne phase remained approximately the same as the subjects in the S

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subgroup. It can be concluded, therefore, that the airborne phase may be dependent on vision and, when the person ran blindfolded, it was dependent on additional factors, such as how adequately the individual had developed the skill of running over the years, the technique used, or how well the person remembered the world, or how safe the runner felt on the course and in the environment in which he was running. The stance phase, on the other hand, appeared to be negatively affected by the use of the guide cable. The stance phase appeared to be even more negatively affected by the combination of both, blindness and use of the guide cable.

The distance that will be covered during the airborne phase is a function not only of time, but of technique, too. For example, BB1, although he had a long enough airborne phase, in terms of time, he had low speed because he was accelerating more upward than forward. In contrast, the length of the stance phase appears to be dependent on both vision and the assisting device used.

Speed is directly related to the stride length (Hay, 1985; Luhtanen & Komi, 1978). Stride length is directly related to the airborne phase and the stance phase. The assisting device confines the arm-leg opposition which contributes to the linear velocity by counteracting the angular momentum of the hips (Hay, 1985; Hinrichs et al., 1983). Therefore, the reasons that the natural speed of the recreational runners who are blind is lower compared to that of sighted subjects, is probably the lack of vision and the assisting device used. Consequently, one way the recreational runners who are blind can increase their speed is by minimizing the contact with the assisting devices so that they can be taught to swing their arms. This must be taken into consideration by

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teachers and coaches when they teach the fundamental motor skill of running. This agrees with the suggestion by Pope et al. (1984) who stressed the importance for runners who are blind to increase the range of motion of the joints of the upper body.

In addition, it was observed that the age at the onset of the disability had an effect on the performance of the cycle lengths of the BB and BA subgroups. The subjects in the BA subgroup had greater percent cycle length in terms of %SHS and %LLL than the subjects in the BB subgroup even when the former ran at lower or similar velocities as the latter. The results of the study showed also that the cycle length of the subjects in the BA subgroup was longer than the cycle length of the subjects in the BB subgroup, but it was comparable in many trials to the cycle length of the subjects in the SB subgroup. The airborne phase of the BB subjects was comparable in many trials to that of the BA subjects (Appendix S). Therefore, differences between the two subject subgroups that affect the stride or, in general, the cycle length, and consequently the running speed, are more likely to appear during the stance phase.

Hypotheses 3 and 4

3. S runners will demonstrate more efficient kinematic patterns, during running than B1 recreational runners.
4. BB runners will demonstrate less efficient kinematic patterns when they run than BA runners.

Ankle Joint

One of the two sighted subjects, and three of the five subjects who were blind were between midfoot and forefoot strikers. BB1 was

forefoot striker. BA3 and S2 were the only subjects who had a rearfoot strike. These proportions do not agree with Cavanagh and Lafortune (1980) and Kerr, Beauchamp, Fisher, and Neil (1983) who found that most runners are rearfoot strikers.

Because most of the subjects were midfoot strikers, there was a tendency for plantar flexion at foot strike from all individuals except SB1. The difference in the degree of plantar flexion at foot strike between subjects BB1 and BB2 was due to the fact that the former was a forefoot striker as if he were a sprinter. His plantar flexion was greater than all subjects and indicated that foot contact was toe first (see Appendix K). Similarly, BA2 demonstrated the second biggest plantar flexion range (see Appendix K). He was a mid-to-forefoot striker.

The angles at the ankle of the subjects in the S subgroup do not agree with those reported in the literature, although they approximate the ones reported by Cavanagh, Pollock, and Landa (1977). For speed comparable to the study, Mann et al. (1986) reported angles ranging from 72° to 78° at foot strike and Cavanagh et al. (1977) reported angles ranging from 96° to 79°. Bates et al. (1977) reported angles at foot strike of approximately 66°, and Smart and Robertson (1985) of 71.2°. The reason that the sighted subject who was a rearfoot striker demonstrated higher values was probably because he was undergoing acceleration. The angles at the ankle at foot strike became smaller for the subjects in the SB subgroup indicating less plantar flexion or more dorsi-flexion accordingly.

Following plantar flexion at foot strike, the angles at the ankle became smaller for all subjects except SB1. Smaller angles indicate dorsi-flexion which was maximum a little after mid-stance for the

subjects who were blind and for the subjects who ran blindfolded. After mid-stance, plantar flexion with the heel rising off the running surface in preparation for toe-off started. This pattern of ankle movement agreed with the literature (Cavanagh et al., 1977; Mann et al., 1986). Mid-stance occurred considerably faster than the middle of the stance phase for the runners who were sighted indicating that they were undergoing acceleration. The angle at the ankle at mid-stance was calculated for all the subjects, but because the sighted runners were accelerating, comparisons cannot be made. Therefore, the minimum angle at the ankle, which indicated maximum dorsi-flexion, was calculated to make comparisons with the angles reported by other investigators (see Table 4.16, and Appendix T).

For the subjects in the BB and in the BA subgroups, the angle of the ankle at maximum dorsi-flexion ranged from 73° to 78°, and from 76° to 86°, respectively. Literature on the sighted runners has shown maximum dorsi-flexion angles to be from 62° to 68° at speed comparable to the study (Mann et al., 1986), and 47° for speeds of 4.5 to 5.0 m/s (Bates et al., 1977). It can be concluded, therefore, that recreational runners who are sighted have greater dorsi-flexion than recreational runners who are blind. In addition, the subjects in the BB subgroup dorsi-flexed more than the subjects in the BA subgroup. Consequently, since maximum dorsi-flexion has been associated with the absorption of the ground reaction forces after the foot strike, it can be observed that the recreational runners in the BA subgroup were more efficient at the ankle joint than their counterparts in the BB subgroup.

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Table 4.16

Maximum ankle dorsi-flexion, and maximum knee flexion (in degrees) during the stance phase for all subjects for five trials.

Subjects	Maximum Dorsi-flexion	Maximum Knee flexion
BB1	73-78 (76)*	142-147 (145)
BB2	73-76 (76)	129-134 (132)
BA1	78-86 (82)	120-124 (121)
BA2	76-81 (79)	132-165 (136)
BA3	79-81 (80)	130-141 (132)
S1	72-77 (73)	115-122 (120)
S2	68-75 (72)	128-132 (129)
SC1	67-75 (69)	111-120 (119)
SC2	71-81 (79)	127-135 (130)
SB1	76-82 (80)	119-123 (122)
SB2	75-80 (79)	130-137 (131)

* = Median values are in parentheses.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

Williams (1980) reported plantar flexion angles at toe-off for sighted individuals running at 3.6 m/s to be approximately 105°. In the present study, all the subjects demonstrated plantar flexion angles greater than those reported in the literature. In addition, it appears from the results of the present study that runners who are blind place greater emphasis on plantar flexion than sighted runners do. This could be the result of, or the reason for, the longer stance phase.

Knee Joint

The results of the present study show that all recreational runners who were blind, independent of subgroup, demonstrated similar knee flexion angles at foot strike ranging from 150° to 161°. The only exception was BA1 who had two out of five trials outside that range. Literature for the runners who were sighted and ran at comparable speeds presented knee flexion at foot strike ranging from 150° to 163° (Bates et al., 1977; Brandell, 1973; Clarke, Cooper, Clarke, & Hamill, 1985; Elliot & Blanksby, 1979; Mann et al., 1986; Smart & Robertson, 1985). These results agree with the findings of the present study. In addition, results reported in the literature agree with the performance of SB2, but not with the performance of S1, SC1, and SB1.

Because researchers reported the maximum knee flexion during the stance phase for sighted runners, and because the results of the present study for the sighted subjects were valid only for runners under acceleration, the maximum knee flexion during the stance phase was calculated for all the subjects (see Table 4.16, and Appendix T). Although the range of knee flexion at mid-stance was comparable between the two subgroups of blind runners, the maximum knee flexion

exhibited great variability among subjects. No common patterns could be seen among subject subgroups.

Literature available on the sighted runners reported values of approximately 125° maximum knee flexion for comparable speeds (Bates, Osternig, Mason, & James, 1979; Bates et al., 1977; Cavanagh et al., 1977; Mann et al., 1986). The results of the present study, except for subject BA1, showed less maximum knee flexion for the subjects that were blind than the maximum knee flexion reported in the literature for sighted individuals. Subject SB1 was close to the maximum knee flexion reported in the literature, whereas subject SB2 was comparable to the results of the subjects who were blind.

It can be concluded, therefore, that since knee flexion is important to absorb the impact of the body with the ground, the recreational runners who are blind, as a group, are less efficient in shock absorption of the GRF than are the sighted runners. This may be attributed to the disability, or to the use of the guide cable, or to the combined effect of the two. There was no noticeable difference in the maximum knee flexion between the subgroups of subjects who were blind.

The knee extension angle at toe-off varied among the subject subgroups. Literature for the sighted runners reports a range of 160° to 173°. This range is in agreement with SB2, and with BA3. In particular, for the subgroup of the BA runners, it appears that knee extension at toe-off is related to the running speed. Subjects BA1 and BA2, who ran at comparable speeds, have almost identical knee extension ranges and medians, whereas subject BA3 who ran at a higher speed has a substantially greater toe-off knee extension angle. However, this relationship is not true for the subjects in the BB subgroup. Rather, it

appears to be a function of the effort the subject made in order to propel himself. Subject BB1's knee was almost straight at toe-off, but the net result for him was vertical acceleration rather than horizontal propulsion, whereas subject BB2, with less knee extension, maintained a greater speed. It is also important to notice that throughout the stance phase the knee joint of the subjects in the BA subgroup flexed for most trials approximately 15° to 30° from foot strike to mid-stance, and from mid-stance to toe-off (see Appendix L). This pattern, as it is reported in the literature, was similar to that of runners who were sighted. For them the range from foot strike to mid-stance was 20° , and from mid-stance to toe-off also 20° (see Table 2.3). It can be concluded, therefore, that recreational runners who are blind are equally efficient in propelling themselves by means of knee extension as their sighted counterparts. In addition, subjects in the BB subgroup, depending on how they apply the knee extension for propulsion, can be as efficient as their counterparts in the BA subgroup. Consequently, it can be added that the subjects in the BA subgroup had better technique in applying knee extension for propulsion.

Hip Joint

Hip flexion at foot strike has been reported in the literature to be 140° to 130° (Mann et al., 1986) or 155.2° to 152.2° (Eliot & Blanksby, 1979). Except for subject BA1, all the subjects who were blind as well as subject S2, running under all conditions, had a common range of hip flexion angles at foot strike of 156° to 152° (see Appendix M). This range was in agreement with the range reported by Eliot and Blanksby (1979).

Consequently, at foot strike, where the shock of impact is absorbed by the hip, the recreational runners who were blind were as efficient as the sighted individuals. Only BA1 had smaller hip angles, and therefore was more flexed at the hip. The hip flexion angles demonstrated by subject BA1 were similar to those reported by Mann et al. (1986). There is no firm suggestion as to why subject BA1 demonstrated this pattern. It is possible that this might be the result of low speed.

After foot strike, the angle at the hip of the supporting leg for all subjects, except BB2 and BA3, was progressively increased from foot strike to mid-stance and from mid-stance to toe-off. Consequently, as soon as the hip joint made its contribution to absorb the impact load, it started moving from a position of flexion, to a position of extension. The reason that subject BA3 did not start to extend until after mid-stance was because he probably had enough momentum to maintain his speed. A different case was demonstrated by subject BB2. He had very little propulsion from plantar flexion and knee extension. However, he maintained a steady speed by continuing to flex from foot strike to mid-stance. By doing this, he achieved greater flexion than the other subjects at the hip joint so that he could extend over a wider range to maintain a steady speed. Indeed, while subjects BA1, BA2, and BA3 extended the thigh over a range of 25° to 34° , which agrees with the literature (Mann et al. 1986), subject BB2 extended over a range of 35° to 45° with an extension range for most of his trials between 41° to 45° . Therefore, individuals make adaptations of this kind in order to compensate for inefficiencies in other aspects of the running cycle.

The literature reports hip extension angles of 197° to 204° at toe-off (Williams, 1980). The results of this study for the recreational

runners who were blind and the SB subjects agree only with the lower limit of this range. That means that, in general, the extension angles at the hip had the tendency to be smaller than those reported for runners who are sighted. This finding points to the suggestion of Arnhold and McGrain (1985), that the individuals who ran under the same visual conditions as the subjects of this study, were using less range of motion at the hip joint. This could be the result of the visual characteristic, or lack of flexibility at the hip joint. The fact that the range of motion at the hip joint of the SB subjects also decreased, points to the suggestion that the decreased range of motion at the hip is likely to be the result of the visual characteristic. However, the decreased range of motion at the hip for the SB subjects could also be the result of fear and insecurity.

Whatever the reason might be, decreased range of motion at the hip joint results in decreased stride length and cycle length which affect the running speed. Therefore, although the recreational runners who are blind may be equally efficient with the sighted individuals at foot strike in terms of the hip flexion, they tend to be less efficient compared to the sighted runners during hip extension at toe-off. In addition, if the reason for decreased range of motion at the hip is less flexibility at the hip joint, the individuals who are blind are under the risk of injury. Lack of hip flexibility can result in larger rotations of the pelvis, which in turn can result in exertion injuries around the hip and the lower back (Wiklander et al., 1987). No difference in hip range of motion was found between the two groups of recreational runners who were blind.

Trunk

The results of this study indicate that the trunk was among the most important parameters that determined the performance of the recreational runners who were blind. The literature has reported that the trunk should be erect for good running form (Slocum & James, 1968). However, other researchers reported runners to lean forward approximately 4° at foot strike (Yoneda, Adrian, Walker, & Dobie, 1979). Subject S2 in the present study demonstrated such a forward lean at foot strike, although his performance was very inconsistent. Following foot strike the forward lean has been reported to increase until mid-stance. For speeds just over 5 m/s, the forward lean reaches a range of 12° to 13° . At toe-off, the trunk inclination is reported to be the same as at foot strike (Yoneda et al., 1979).

In the present study, nearly all the recreational runners who were blind had a negative inclination of the trunk at foot strike (see Figures 4.24, and 4.25). Only subject BA1 demonstrated a positive inclination of the trunk. That subject, however, revealed to the investigator after the biomechanical evaluation that, when he was being filmed, he "tried to look as less blind as possible" despite our instructions to run naturally. The backward lean of the trunk increases the backward rotating effect of the horizontal component of the GRF resulting in decreased speed.

From foot strike to mid-stance the runners who were blind made a transition from backward inclination of the trunk to forward inclination of the trunk. The degree of forward inclination varied so that no pattern could be observed either for the runners who were blind as a whole or specifically to each subgroup. Consequently, like the sighted subjects,

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the subjects who were blind increased their forward lean from foot strike to mid-stance.

From mid-stance to toe-off, the trunk angle of inclination from the vertical increased or remained almost the same for the subjects who were blind. On the contrary, the trunk angle of inclination of the sighted runners, as reported in the literature, decreased back to the values they had at foot strike. The performance in the inclination of the trunk is an indication of the poor running posture on the part of the runners who were blind, which is probably associated with the lower velocities demonstrated.

It can be concluded, therefore, that a major lack of efficiency in the running technique and performance of the recreational runners who are blind occurs as a result of poor posture. The fact that poor posture is the result of less efficient ambulation, demonstrated by the individuals who are blind, has been supported by Dawson (1981) who studied the walking gait of persons who were blind. The backward lean of the trunk was also found by Gorton and Gavron (1987) who studied sprinters who were blind. However, contrary to the results of the present study, they found the backward lean of the trunk to remain the same throughout the entire stride. A possible reason for this difference is the velocity of the performance. The present study found no substantial differences in trunk inclination between the two classification groups of the recreational runners who were blind. In addition, no conclusions can be drawn from the performance of the sighted subjects who ran under the SB running condition. The performance of SB1 was in every aspect opposite to the performance of SB2.

Head and Neck

Careful examination of the data obtained about the head and neck angle combined with the head inclination data indicate that neck movement is possibly the most important parameter in this study that explains the performance of the recreational athletes who were blind. The movement of the neck throughout the stance phase has not been examined by other researchers.

The head and neck angle varied among the subject groups, and subgroups. The pattern appeared to be different for the subjects in each subgroup of recreational runners who were blind. The subjects in the BB subgroup increased their head and neck angle from foot strike to mid-stance and decreased it from mid-stance to toe-off. The subjects in the BA subgroup maintained approximately the same head and neck angle from foot strike to mid-stance, or increased it, but less compared to the BB subgroup. From mid-stance to toe-off the subjects in the BA subgroup increased the angle between the head and neck. The subjects in the SB subgroup demonstrated a progressive increase of the head and neck angle from foot strike to toe-off.

The data from the inclination of the head indicated that the subjects in the BB subgroup kept their heads back at foot strike and toe-off. At mid-stance, subject BB1 kept his head back, whereas BB2 had his head forward. Two of the three BA subjects demonstrated positive head inclination at foot strike. During mid-stance and toe-off, two of the same three subjects maintained a negative angle of inclination. Only BA1 maintained a positive inclination angle of the head. After the end of the test in a conversation between BA1 and the investigator, the subject revealed that he "tried to look as less blind as possible" although he was

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asked to run as naturally as possible. He described specifically his upper body performance and especially that of the head. His description portrayed a head inclination pattern as that of subject BA3. The fact that subject BA1 maintained consciously a positive head inclination could be the effect of training. Subject BA1 had more structured coaching, practical and verbal, than the other subjects who were blind. Therefore, it can be concluded that efficient training can improve the running pattern of the recreational runners who are blind.

The difference in the inclination of the head at foot strike may be due to the age at onset of blindness. BA individuals lose their sight gradually over the years. As their sight becomes worse, they look down in preparation for foot-strike, so that they can make sure where to place their foot (Dr. Poncillio, personal communication, April, 1992). This becomes part of their gait pattern. The results of the present study indicate that two of the three subjects in this classification had the tendency to tilt their heads forward at foot strike.

However, in order for the data presented above to make sense, it is important that a distinction is made. Unlike the other researchers, who examined the movement of the head and the neck as one body segment (Dawson, 1981; Pope et al., 1984; Arnhold & McGrain, 1985; Gorton & Gavron, 1987), the results of the present study indicate that the neck needs to be treated as a separate body segment. Its function during the stance phase is independent, but at the same time combined with that of the head and the trunk.

At toe-off, the head of all the individuals who were blind was tilted back. The neck was also pulled back relative to foot strike. The cinematography revealed that after toe-off all the subjects kept their

head and neck back for the most part of the recovery phase.

Consequently, the trunk was extended and inclined backward immediately following toe-off instead of keeping its forward inclination, as is the case with the sighted individuals (Slocum & James, 1968; Yoneda et al., 1979). After the first half of the recovery, the BA subjects brought the head and the neck forward. That forward movement of head and neck might be a custom to "see" or make sure as to where the foot is going to be placed. The subjects in the BB subgroup brought the neck forward just before foot strike while keeping the head back. However, the BB subjects, just prior to foot strike, brought their neck back in preparation for foot strike. The subjects in the BB subgroup kept their head back until after foot strike, and they pulled their neck back from foot strike to mid-stance. It is possible that this is a mechanism to protect the head from any possible obstacles. Subject BB2, in particular, was turning his head completely to the side at every foot strike as if he wanted to minimize the effect of collision with possible obstacles. The subjects of the BA subgroup also pulled their neck back from foot strike to mid-stance. The pulling back of the neck could also be a mechanism for this subgroup to protect the head from possible obstacles. Since the pulling back of the neck probably resulted in slowing down the body's forward momentum, it could also be a mechanism to protect the body from or to minimize the body's collision with any possible obstacles. After heel-strike, the body kept moving forward due to the momentum.

After mid-stance, and before toe-off, all the subjects had their neck forward. However, the subjects in the BB subgroup had their neck forward until a little after mid-stance. The subjects in the BA subgroup, in most of their trials, had their neck forward until toe-off. In addition,

in most of their trials, they brought their head forward relative to the mid-stance in preparation for toe-off (see Appendix P). However, at toe-off, the heads of the subjects BA2 and BA3 were still tilted back. The heads of the subjects in the BB subgroup were also still tilted back at toe-off. It was also noticed that subjects BA1 and BA3, for two of their trials, pulled the neck back after foot strike to reach a maximum angle at mid-stance. Following mid-stance the neck was brought slightly forward, but, relative to foot strike, it was still pulled back at toe-off.

The independent movement of the neck is the only explanation of the observation that the negative inclination of the head increased while the relative angle between the head and the neck increased or remained approximately the same. Figures 4.21 and 4.22 illustrate the above discussion.

In the light of the above discussion, the recreational runners who were blind appeared to be less efficient than sighted runners. This may be due to the disability itself or due to the conditions under which they ran (i.e., they used a guide cable) or to a combination of both. In addition, because these findings appeared to be the reason for the differences in performance between the subjects in the BB subgroup and the subjects in the BA subgroup, it is concluded that the performance of the former is less efficient than the performance of the latter. It can also be concluded, that correct running technique and posture for the recreational runners who are blind may depend on the teaching and coaching of the correct head and neck positions.

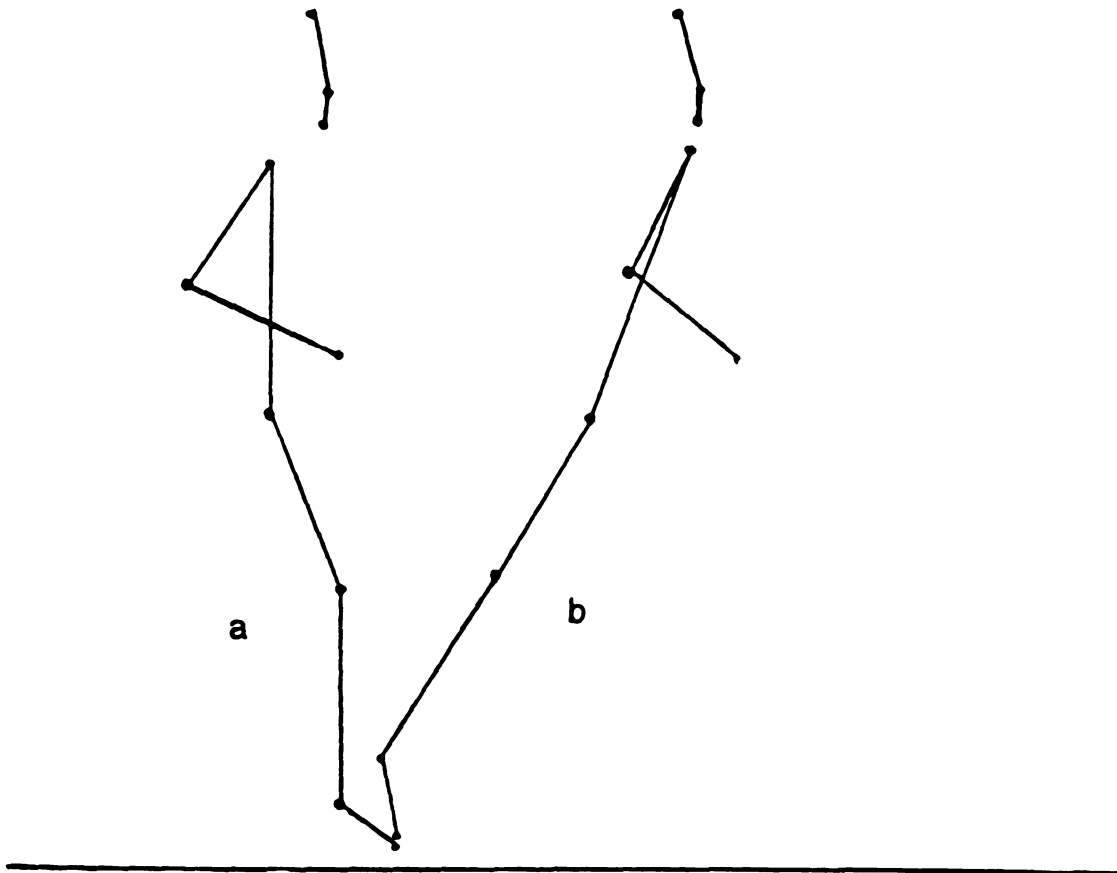


Figure 4.21

The kinematics of recreational runners who were blind. The recreational runners who were blind before five years of age kept their heads back throughout the entire support phase: a) foot strike and, b) toe-off.

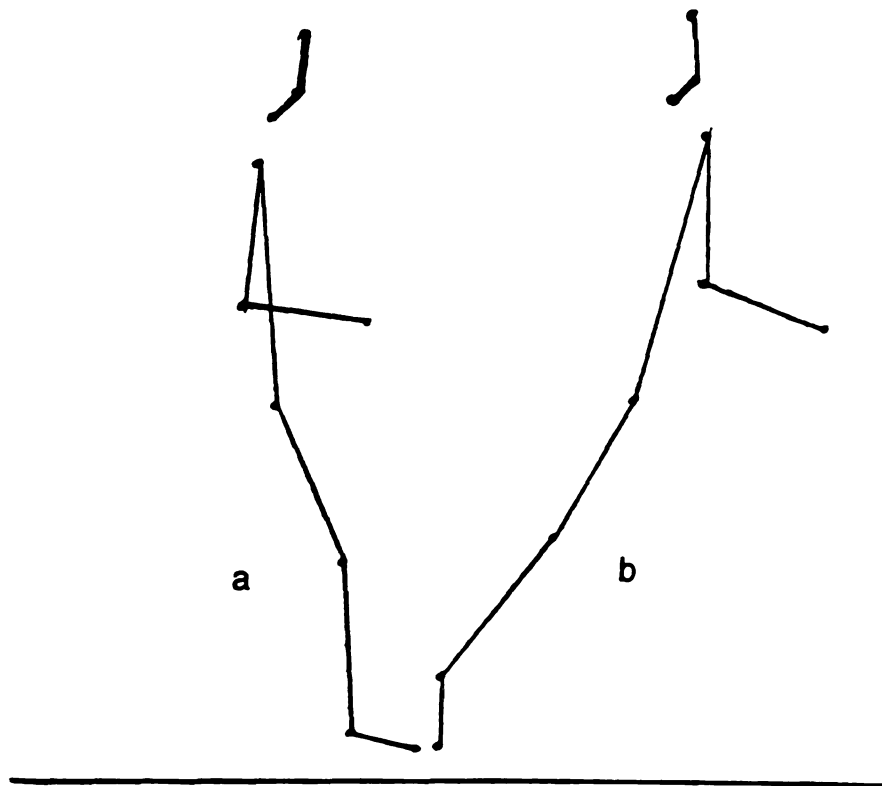


Figure 4.22

The kinematics of recreational runners who were blind. Most of the recreational runners who became blind after five years of age demonstrated positive head inclination at foot strike (a). During the rest of the support phase, they maintained negative angle of head inclination (b).

Shoulder Joint

The results from the shoulder flexion extension data indicate that there is flexion and extension at the shoulder joint under all running conditions and for all the subjects. The degree of flexion/extension at the shoulder was comparable for the groups of recreational runners who were blind.

However, the sighted recreational runners under accelerating conditions demonstrated a wider flexion-extension at the shoulder joint. The range of movement was reduced when they ran under the SC and SB running conditions. When they ran under the SB running condition, the range of flexion-extension at the shoulder was slightly larger than that of the recreational runners who were blind. Therefore, the use of the guide cable appears to have a restrictive influence on the flexion-extension at the shoulder. In addition, the range of flexion-extension at the shoulder may not be entirely due to movement at the shoulder joint. It may be in part due to trunk rotation. It appears, therefore, that the trunk functions in a way to replace the shoulder flexion-extension of the arm that holds the rope of the baton. Consequently, it is implied that the flexibility of the upper body of the recreational runners who are blind and who use assistive devices is very important to counteract the angular momentum of the hip. It also may be that the individuals who are blind need to be encouraged and taught to swing the arm that holds the rope of the baton through which the guide cable is threaded. It also implies that there should be an effort to minimize contact with an assistive device in order to increase the range of flexion-extension of the arms to counteract the angular momentum of the hips. Figures 4.21 through 4.24 illustrate the kinematics of recreational runners who were blind, and the kinematics of the sighted recreational runners when they ran blindfolded.

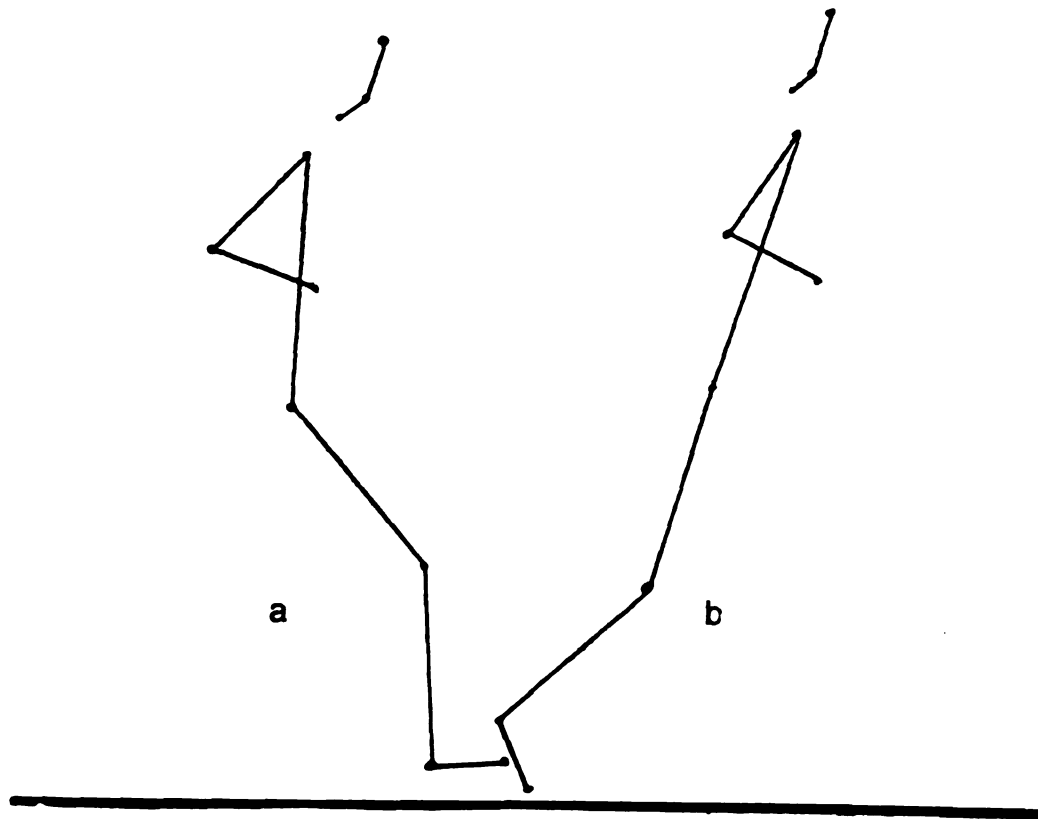


Figure 4.23

The kinematics of Subject SB1 when he ran blindfolded: a) foot strike and b) toe-off.

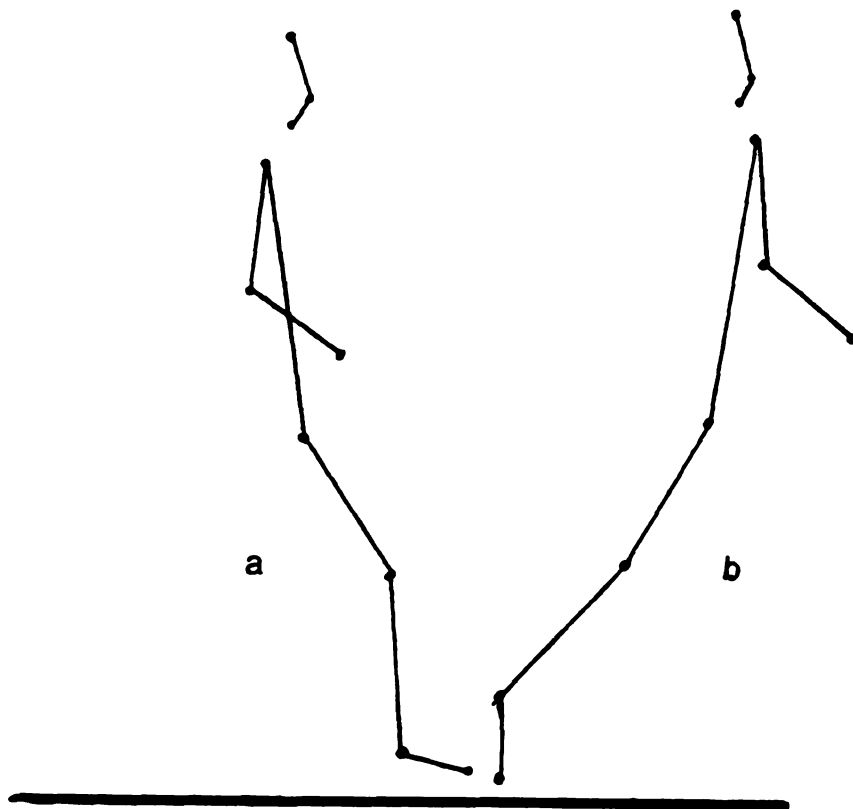


Figure 4.24

The kinematics of Subject SB2 when he ran blindfolded: a) foot strike and b) toe-off.

Hypothesis 5 and 6

5. At similar velocities, B1 recreational runners, in general, will experience greater ground reaction forces, relative to their body weight, when they run than do S runners.

6. At similar velocities, BB runners will experience greater ground reaction forces, relative to their body weight, when they run than will BA runners.

Vertical Ground Reaction Force

Literature on the running technique of the sighted population has classified runners as rearfoot, midfoot, and forefoot according to the part of the foot that contacts the ground first (Cavanagh, 1981; Cavanagh & Lafortune, 1980; Munro et al., 1987). It has also been reported that for midfoot or forefoot strikers, the impact peak is attenuated or is absent (Cavanagh & Lafortune, 1980; Clarke et al., 1983). However, these results do not agree with the findings of the present study about the recreational runners who were blind. Figures 4.25, 4.26, and 4.27 present the vertical component of the GRF of subjects BB1, BA1, and BA2 who were forefoot, midfoot, and midfoot to forefoot strikers, respectively (see pp 59-61, Chapter III for explanation of GRF graphs). In addition, the vertical component of the GRF of subject S2, who is sighted and a midfoot striker, is presented in Figure 4.28. Although it has been shown that he was running under accelerating conditions, he demonstrated the attenuation of the impact peak as a midfoot striker that the literature has reported.

Observation of Figures 4.25 through 4.28 in conjunction with relevant reports in the literature for the sighted runners, leads to the conclusion

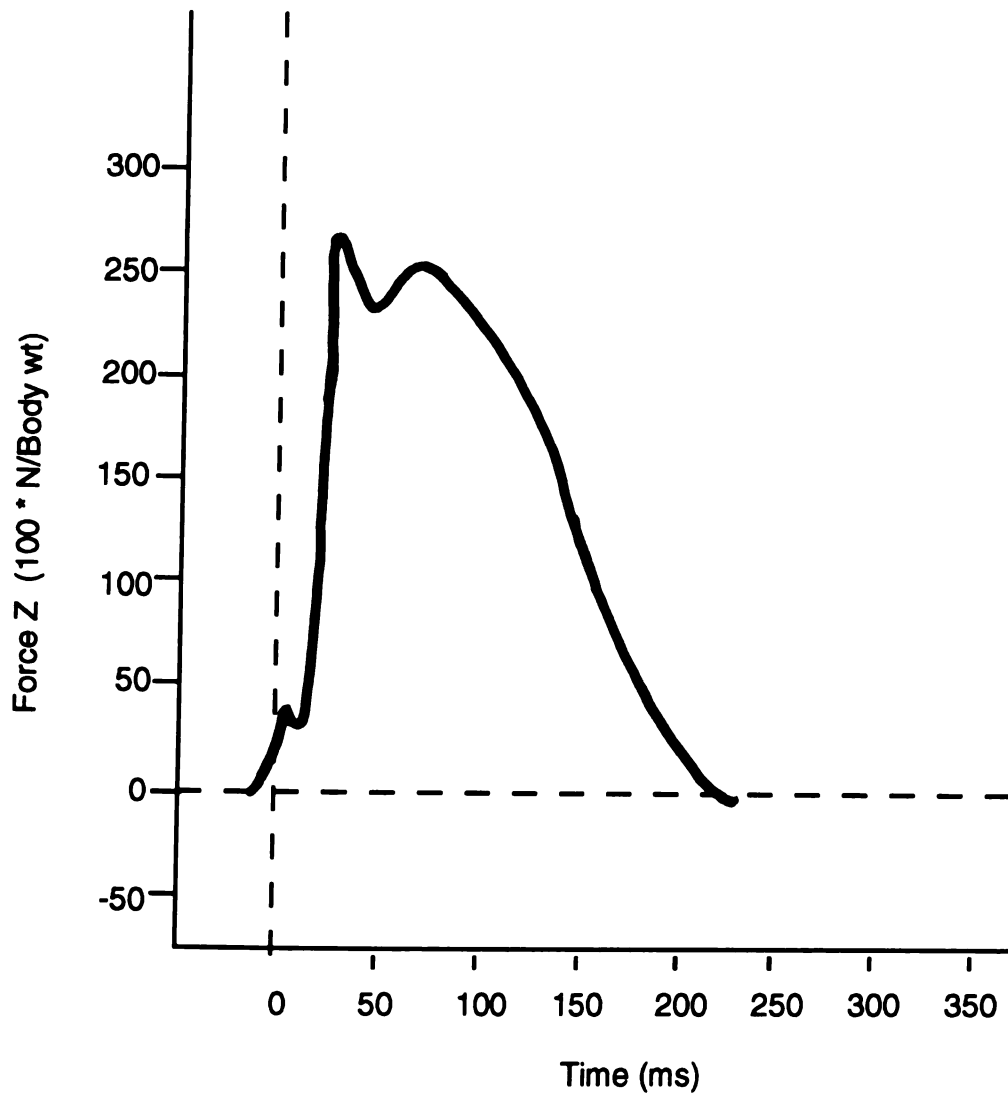


Figure 4.25

The vertical component of the GRF of Subject BB1 who became blind before the age of five years, and is a forefoot striker.

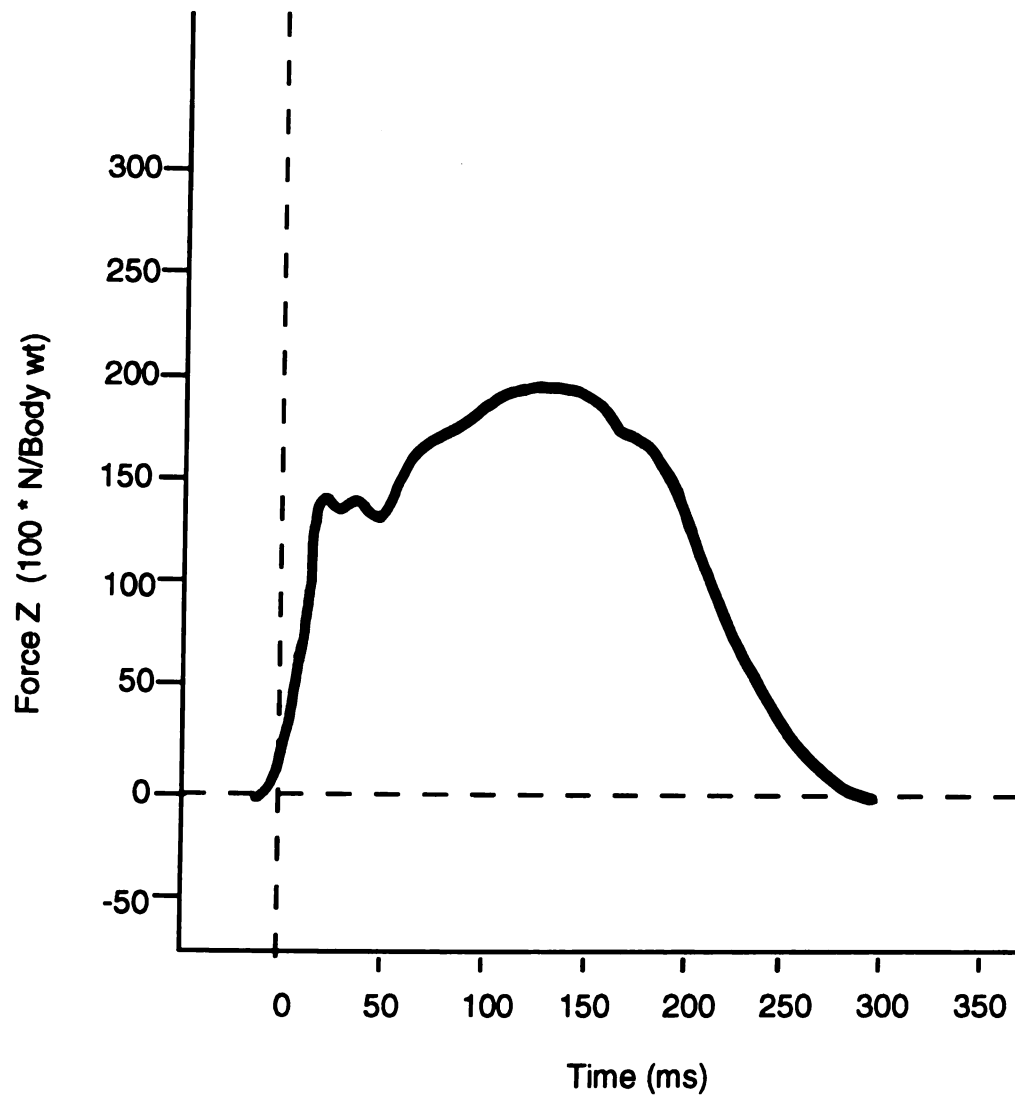


Figure 4.26
The vertical component of the GRF of Subject BA1 who became blind after the age of five and is a midfoot striker.

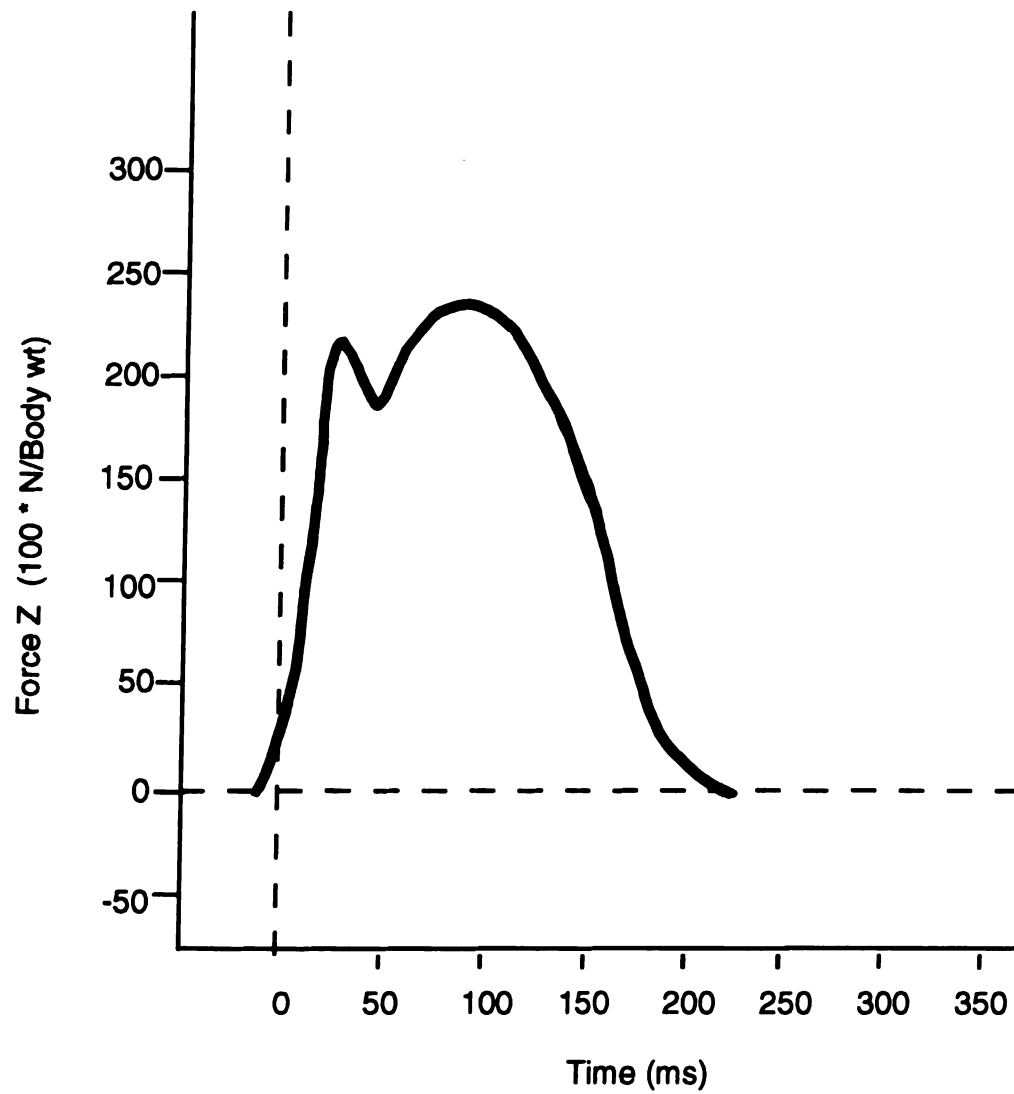


Figure 4.27

The vertical component of the GRF of Subject BA2 who became blind after the age of five and is a mid- to forefoot striker.

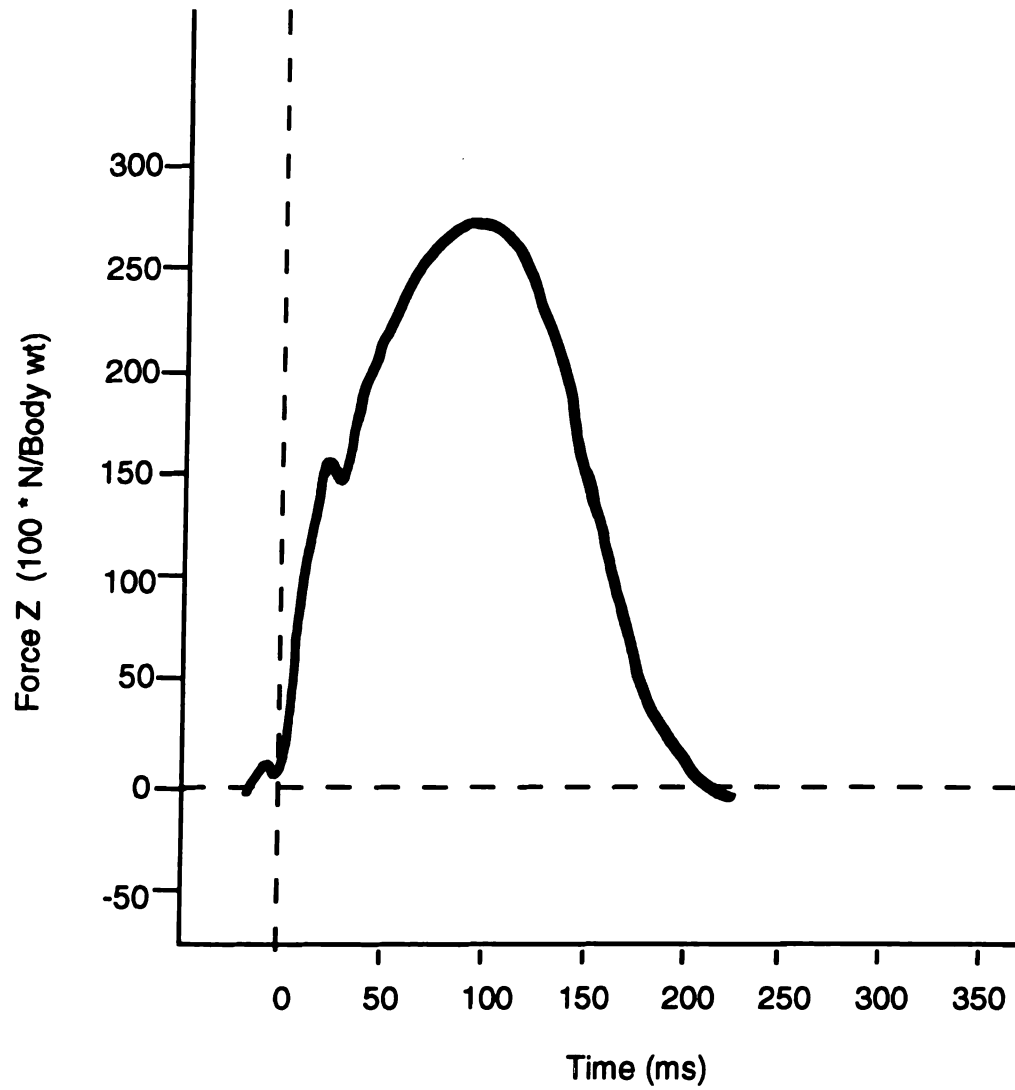


Figure 4.28
The vertical component of the GRF of Subject S2 who is sighted and a midfoot striker.

that the kinetic patterns of recreational runners who are blind cannot be compared with sighted populations because, under the same conditions, they perform with different standards. It is possible that the reason the runners who were blind demonstrated an impact peak, even if they were midfoot strikers, is the negative inclination of the trunk which is caused by the position of the neck. Figure 4.29 shows the vertical component of subject SB2. He presented an impact peak force under this condition, and, as film analysis showed, he changed from a midfoot striker when he ran under the S and SC running conditions to a rearfoot striker when he ran under the SB running condition. The reason that three of the runners who were blind in this study used a midfoot strike approach may be a natural adjustment in order to minimize the vertical forces they were about to experience as the result of their posture. Another reason may be that they wanted to use the leading foot as a probe. This last view is supported by Dawson (1981).

During the presentation of the results earlier in the chapter, it was noted that there were different performances between the dominant and the nondominant leg. The same was observed when the GRFs were investigated.

Examination of the vertical component of the GRF shows that the subjects in the BB subgroup, experienced higher decelerating forces than those reported in the literature for sighted runners running at comparable speeds (Munro et al., 1987). In fact, the maximum decelerating forces for the dominant and nondominant leg experienced by the subjects in the BB subgroup, appear to be comparable with results reported in the literature on subjects who have been tested at speeds of approximately 4.5 m/s and higher (Cavanagh & Lafortune, 1980; Clarke et

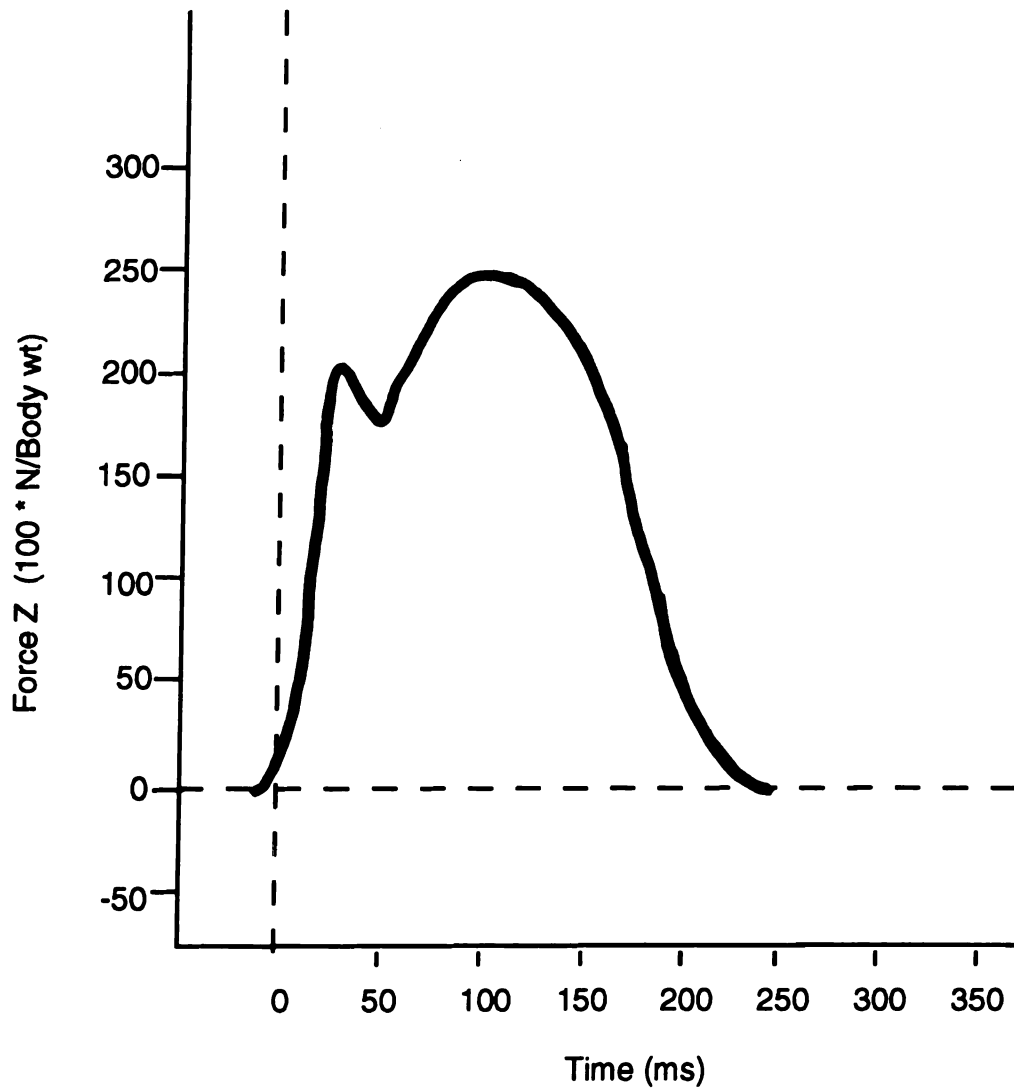


Figure 4.29

The vertical component of the GRF of the sighted Subject SB2 when he ran blindfolded.

al., 1983; Hamill et al., 1983). Maximum deceleration, however, occurred faster in time and percent stance phase in these studies than it occurred in the present study for runners who were blind. In the present study it occurred up to 33 ms.

Nigg et al. (1987) and Nigg (1983) reported that the impact peak force is responsible for many of the running injuries since it has to be absorbed by the body faster than the time the body needs to recruit its best shock absorbers, the muscles. Consequently, subjects in the BB subgroup are exposed, although to a lesser extent than the sighted individuals, to the likelihood of injury. The subjects in the BA subgroup, were exposed to the likelihood of injury to a lesser extent than the subjects in the BB subgroup. Maximum deceleration occurred later in time and in percent of stance phase for the dominant leg. The only exception in this subgroup was subject BA3 who ran faster than all the other subjects who were blind. Therefore, he experienced higher decelerating forces which occurred faster in time and earlier in percent stance phase (see Figures 4.30, 4.31a and 4.31b).

The maximum unloading force indicates a runner's ability to absorb the load of the impact. In maximum unloading the recreational runners who were blind, in general, were less efficient than the sighted runners because they did not use as much range of motion in their lower limb joints to absorb the load of the downward deceleration force. Maybe that could be achieved had they not used a guide cable, or had they received appropriate training instructions in the past. The sighted runners, as reported in the literature, for comparable and faster speeds had maximum unloading values of approximately 1.2 BW occurring at 11.5 to 15.6 percent of the stance phase (De Vita & Bates, 1988; Hamill et al.,

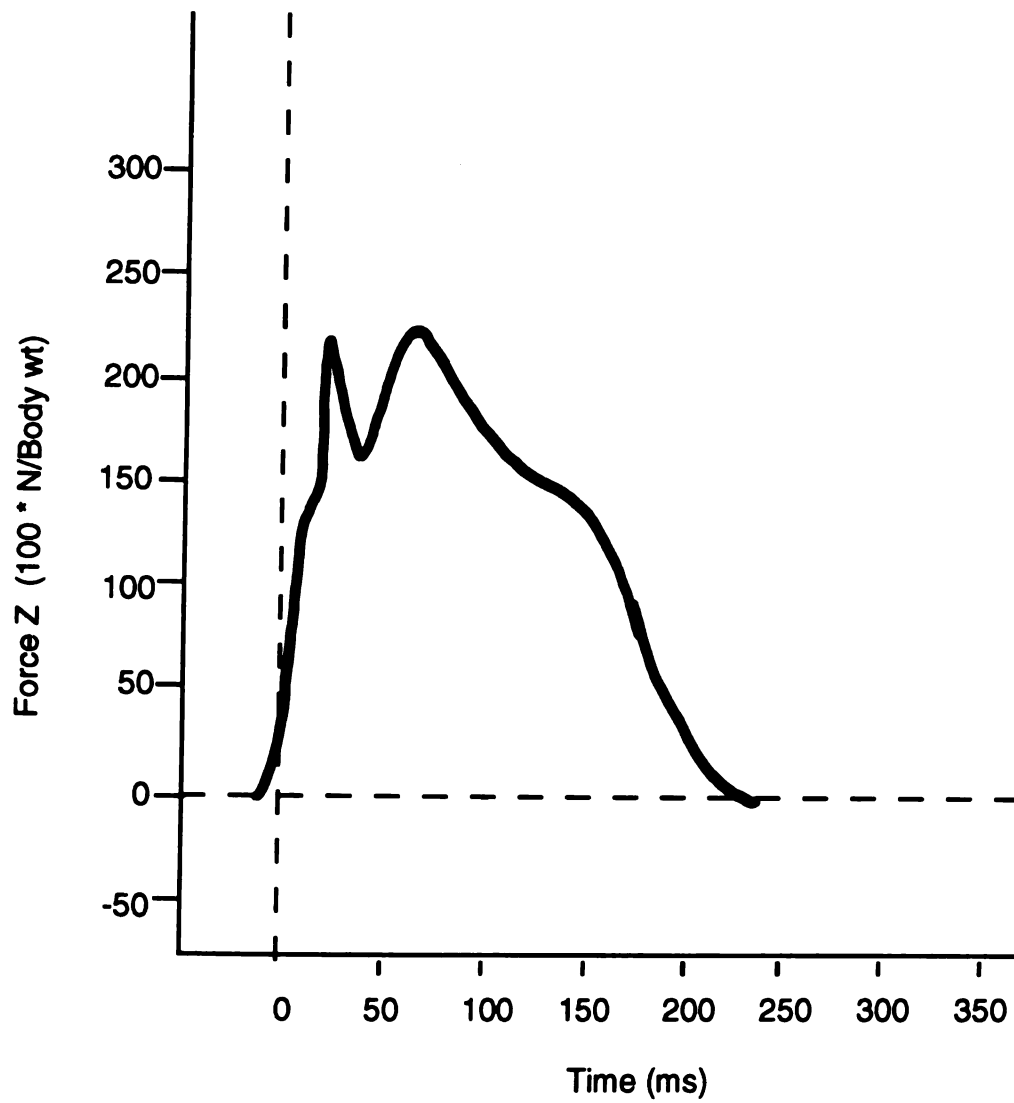


Figure 4.30

The vertical component of the GRF experienced by the dominant leg of Subject BB2 who was blind before the age of five years.

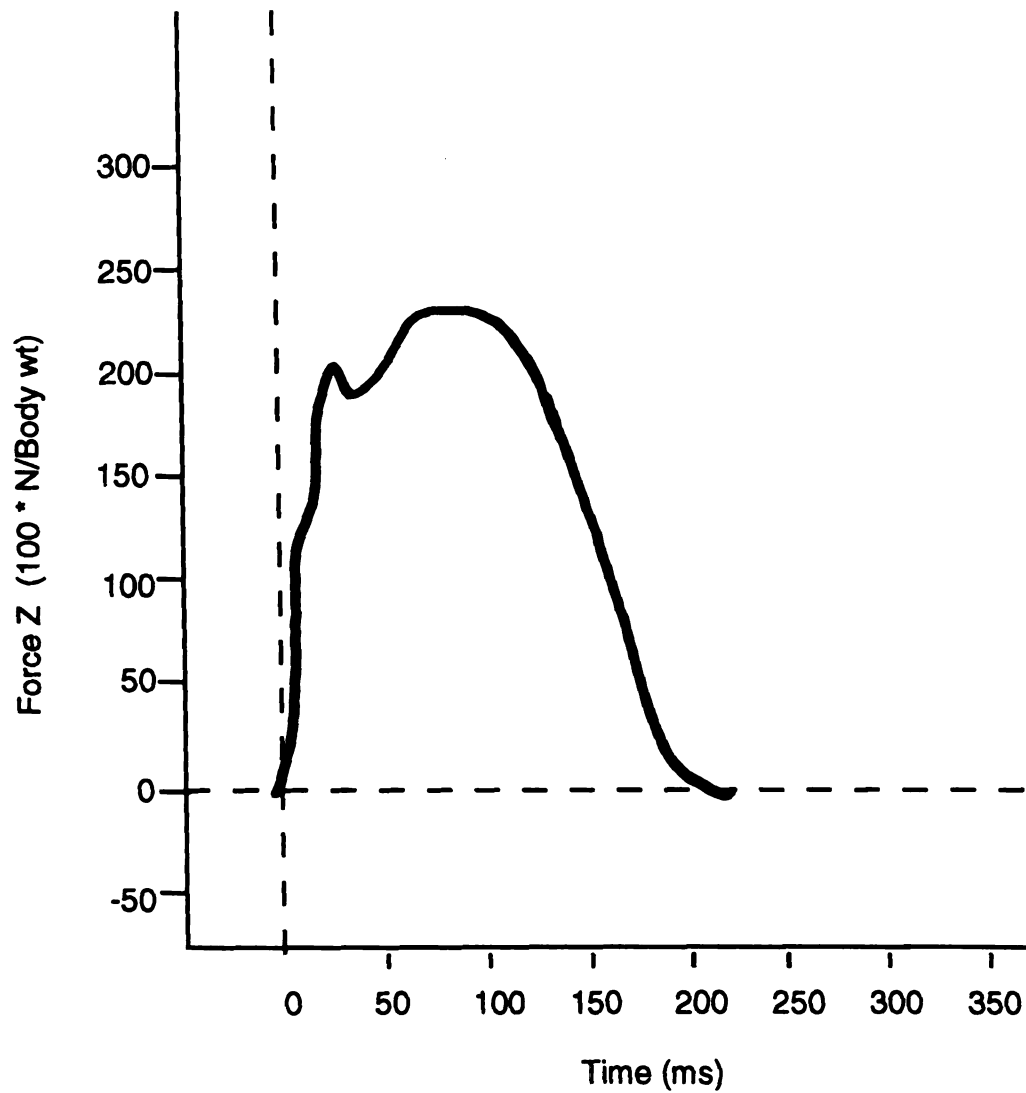


Figure 4.31a
The vertical component of the GRF experienced by the dominant leg of Subject BA2 who became blind after the age of five years.

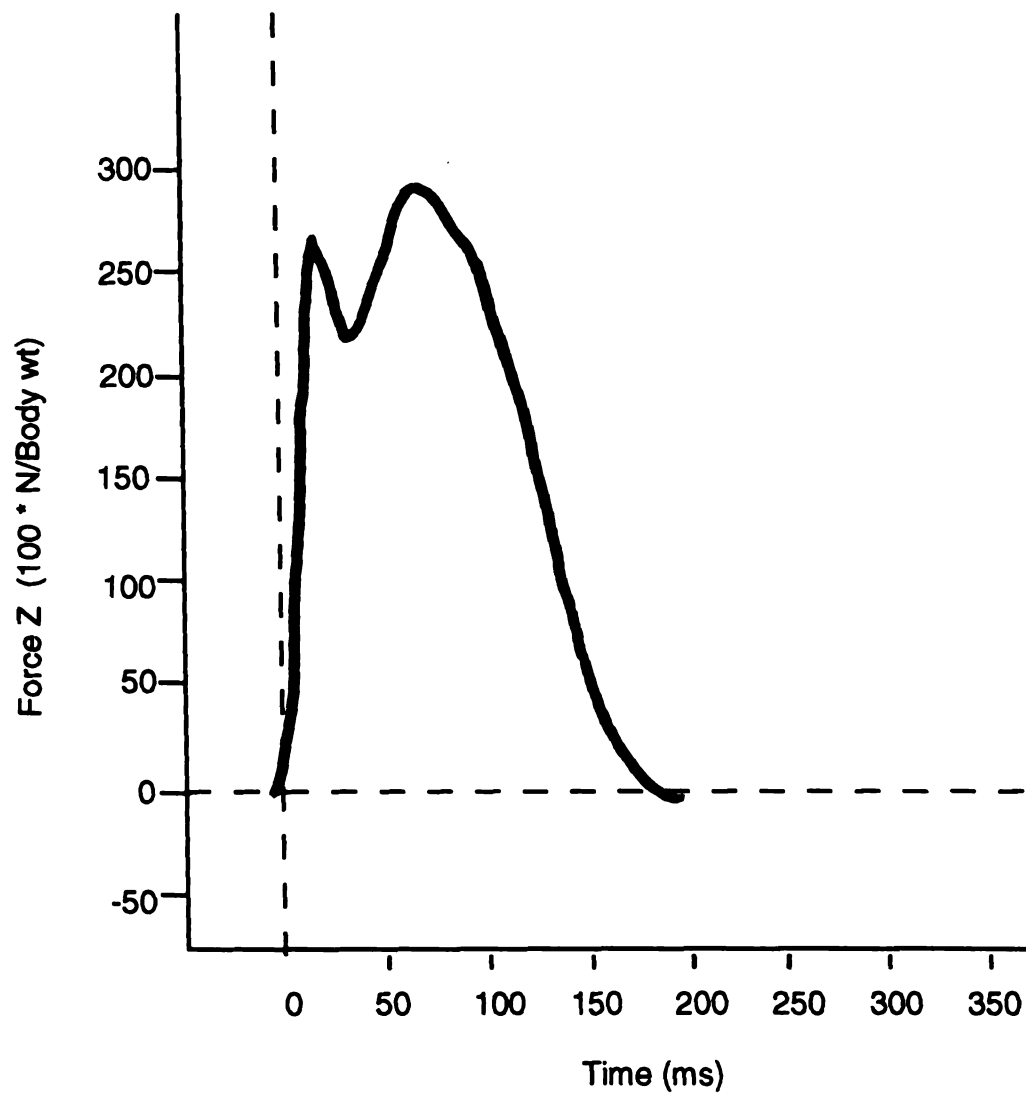


Figure 4.31b
The vertical component of the GRF experienced by the dominant leg of Subject BA3 the recreational runner who became blind after the age of five years.

1983; Munro et al., 1987). The nondominant leg of each of the runners in the BB subgroup had the best performance experiencing loads from 1.35 to 2.27 BW.

The subjects in the BA subgroup were more efficient than the subjects in the BB subgroup, at least in the forces experienced by the dominant leg. Most of the maximum unloading values of the subjects in the BA subgroup were less than those experienced by the subjects in the BB subgroup. The lower maximum unloading values experienced by the dominant leg of the BA individuals indicates that BA recreational runners are likely to use their ankle, knee, and hip joints more during the stance phase than are BB runners.

During maximum acceleration, in general, the recreational runners who were blind were less efficient than the sighted runners who, based on the results reported in the literature, apply higher vertical acceleration forces and therefore have longer airborne phases (Cavanagh & LaFortune, 1980; Munro et al., 1987; Roy, 1982). The lesser vertical acceleration values can account for the shorter stride and cycle length of the recreational runners who were blind. The results of the study also indicated that runners who were blind were less efficient in using the hip, knee, and ankle range of motion to experience higher maximum accelerating forces. Exceptions were subjects BB1 and BA3. They experienced high vertical accelerations and demonstrated the longest airborne phases which were the result of the more efficient use of the lower limb joints. However, the lower vertical acceleration forces demonstrated by the group of the runners who were blind might also be due to their will to keep the center of gravity low so that they can maintain a shorter, but more stable stride. That suggestion could justify

the observation from film analysis that the three subjects (BB2, BA1 and BA2) with the lower accelerating values flexed very little at the hip during the recovery of each leg. If the goal of recreational runners who are blind is to increase stability by keeping the center of gravity low, then their vertical acceleration force pattern is efficient with respect to their goal.

Teaching recreational athletes and building up their confidence in order to utilize the full range of motion in their joints is very important to improve their performance and minimize the likelihood of injury. The variability in the performance of the maximum acceleration of each subject in each group did not allow for the observation of any pattern between the subject groups of runners who were blind.

Examination of the vertical component during the stance phase revealed that the sighted subjects had totally different performances. Therefore, no conclusion could be made other than that sighted subjects who are deprived of their vision momentarily can not be compared with the population who is blind.

In general, the BB subjects experienced higher rates of loading than the BA subjects who were running at comparable velocities. Therefore, they were exposed to a higher risk of injury. In addition, it was observed that two of the three BA subjects had loading rates within the norms defined by Munro et al. (1987). Subject BA3, however, was experiencing very high rates of loading. That meant that he was more exposed to the risk of injury. Subject BB1's rate of loading was within the norms, but toward the higher limits. Subject BB2, however, was exposed to the risk of injury since his rate of loading was very high compared to other results available in the literature for sighted runners (Munro et

al.,1987). It was also observed that the highest rates of loading occurred in the nondominant leg. This observation indicates that, if injury were to occur, it would be more likely to occur in the nondominant leg.

Anterior-posterior Ground Reaction Force

The recreational runners who were blind demonstrated a biphasic anterior-posterior curve which consisted of a braking phase, and a propulsive phase. The shapes of the curves reported in the literature for sighted runners (Cavanagh, 1981; Cavanagh & Lafortune, 1980; Hamill et al., 1983; Munro et al., 1987) agree with those of the present study . The subjects of the present study who were midfoot strikers demonstrated two peaks during the braking phase; whereas, the subjects who were rearfoot strikers demonstrated only one braking peak. This was consistent with the reports of Cavanagh and Lafortune (1980) for sighted runners. However, in the present study, two subjects in the BA subgroup demonstrated patterns that deviated from what has been reported. Subject BA1, who was a midfoot striker, demonstrated one braking peak with his nondominant leg, and BA3 had a tendency for double braking peak with his nondominant leg (see Figure 4.32). This difference could not be explained. However, it points to the suggestion of Munro et al. (1987) that the double peak brake is not always a characteristic of the midfoot strikers.

In the present study, in general, the recreational runners who were blind experienced higher peak braking forces at lower speeds than those reported in the literature for sighted subjects running at higher speeds. Cavanagh and Lafortune (1980), reported values for peak brake of 0.43

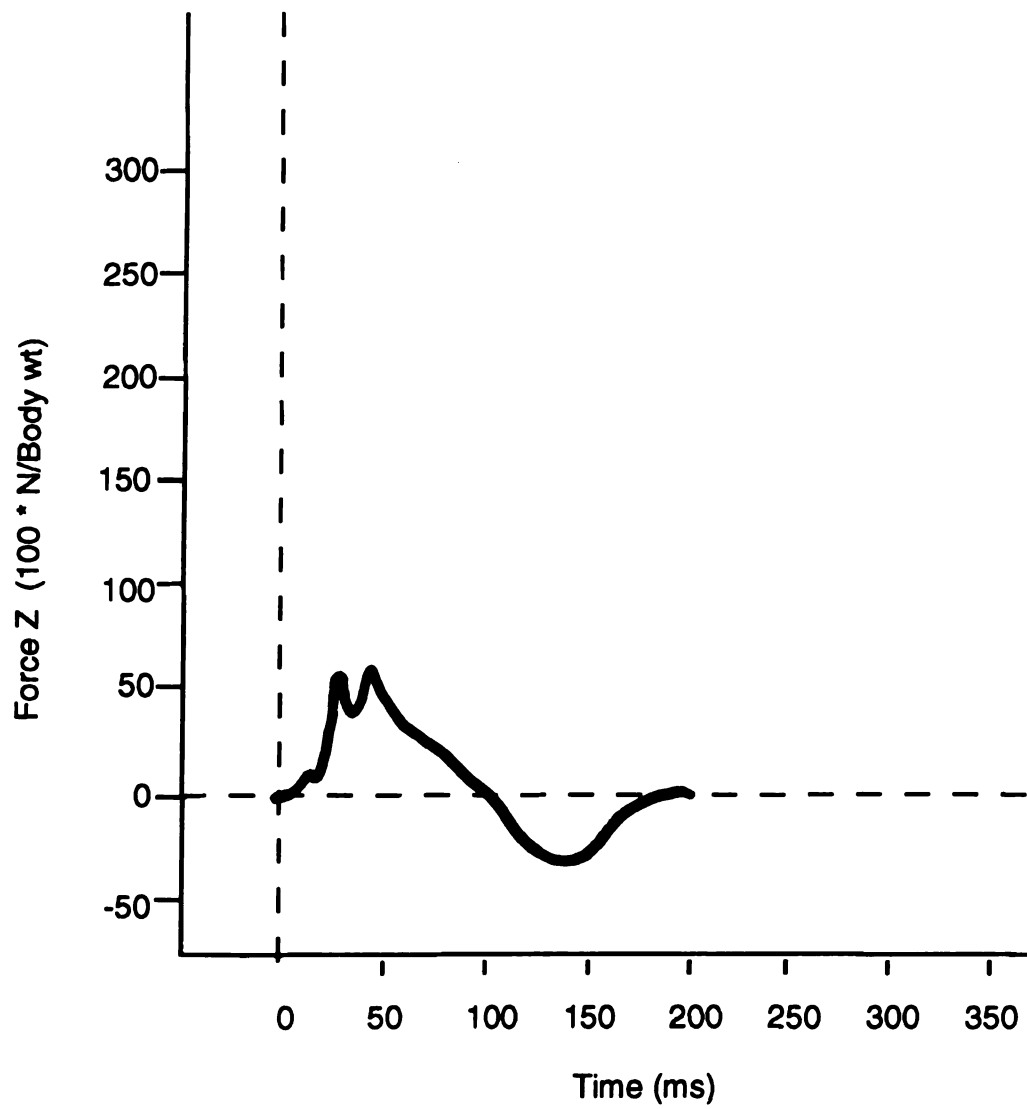


Figure 4.32
Tendency for double braking peak of BA3 who became blind after the age of five, and a rearfoot striker.

BW for rearfoot strikers, occurring at 46 ms, and 0.45 BW for midfoot strikers occurring at 11 and 38 ms for individuals running at 4.5 m/s. Munro et al. (1987) reported single peak brakes of 0.15 to 0.25 BW to occur at 25 percent of the stance phase or at 17 and 24 percent of the stance phase for double peak brakes of sighted runners running at 3.5 m/s. The occurrence of the maximum braking peak in percent of stance phase, agreed with Hamill et al. (1983) for sighted runners running at 4 m/s. The higher braking forces experienced by the group of blind runners in the present study were probably due to the trunk inclination at foot strike, which is the result of the neck and of the head position at toe-off, and during the recovery phase. The inclination of the trunk causes the runner's center of gravity to fall relatively far behind the foot contact, increasing, therefore, the retarding force to forward motion. Consequently, teaching runners who are blind the correct running posture is important in order for them to be more efficient.

In the present study, the transition from the braking to the propulsive phase occurred earlier for most trials of the recreational runners who were blind, especially for the BB subjects, than it occurred for the sighted runners. Although in other studies the running velocity was greater than in the present study, the transition from the braking to the propulsive phase has been reported to occur at 48-49.9 percent stance phase (Cavanagh & Lafortune, 1980; Hamill et al., 1983; Munro et al., 1987).

The peak propulsive values of the present study for the recreational runners who were blind, were higher than the ranges reported by the literature for the sighted runners running at higher velocities (Cavanagh & Lafortune, 1980; Hamill et al., 1983; Munro et al., 1987; Roy, 1982).

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The fact that the recreational runners who were blind ran at lower velocities although they produced higher propulsive forces over longer periods, since their transition occurred generally earlier, indicates that they were less efficient than the sighted runners and that they experienced more energy expenditure. This may be due either to the disability, or the use of the guide cable, or the combination of both. However, learning or making adjustments, e.g. not using a guide cable, to perform the correct running technique is very important in order to maximize running efficiency. This concept is discussed later when impulses are examined. The peak propulsive values, however, occurred later in the runners who were blind. A possible reason is that the sighted subjects performed at higher velocities. Another reason may be that, because of the poor running posture, the relative time the runners who were blind needed from foot contact to maximum propulsion was longer than the time the sighted runners needed from foot contact to maximum propulsion.

For the subjects in the BA subgroup, it was observed that the dominant leg produced higher propulsive forces than the nondominant leg. As a consequence, and due to the body posture, the nondominant leg experienced the high braking forces and it produced lower propulsive forces (see Figure 4.33a, 4.33b). The opposite, however, was true for the subjects in the BB subgroup. The subjects in the BB subgroup had earlier transition time, particularly in the nondominant leg, compared to the subjects in the BA subgroup. Consequently, the nondominant leg was responsible for the high propulsive forces, and the dominant leg was experiencing the higher decelerating forces. Although, the peak propulsive values were less for the BB subjects, the speed was

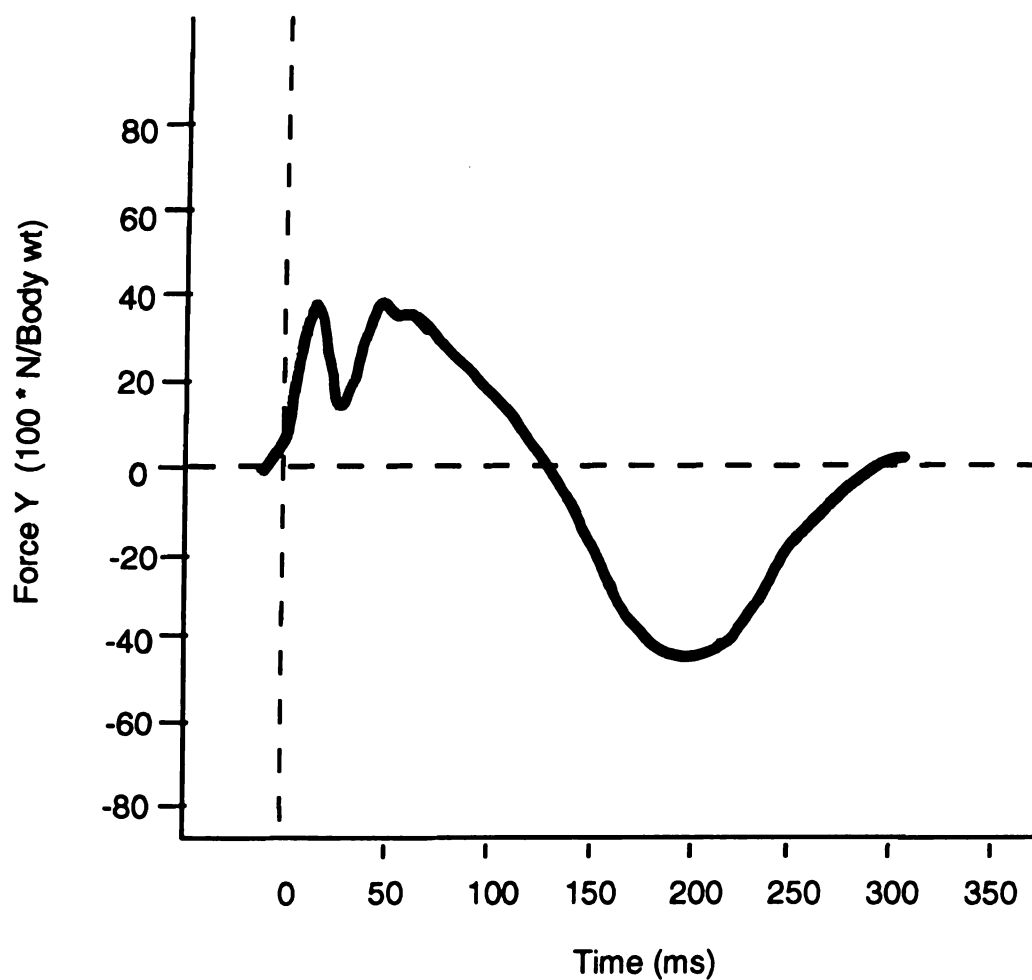


Figure 4.33a

This is a common anterior-posterior force experience of the dominant leg of a subject in the group of recreational runners who were blind. The dominant leg, in most cases, produced high propulsive forces over longer periods of time. The nondominant leg experienced high braking forces and produced lower propulsive forces.

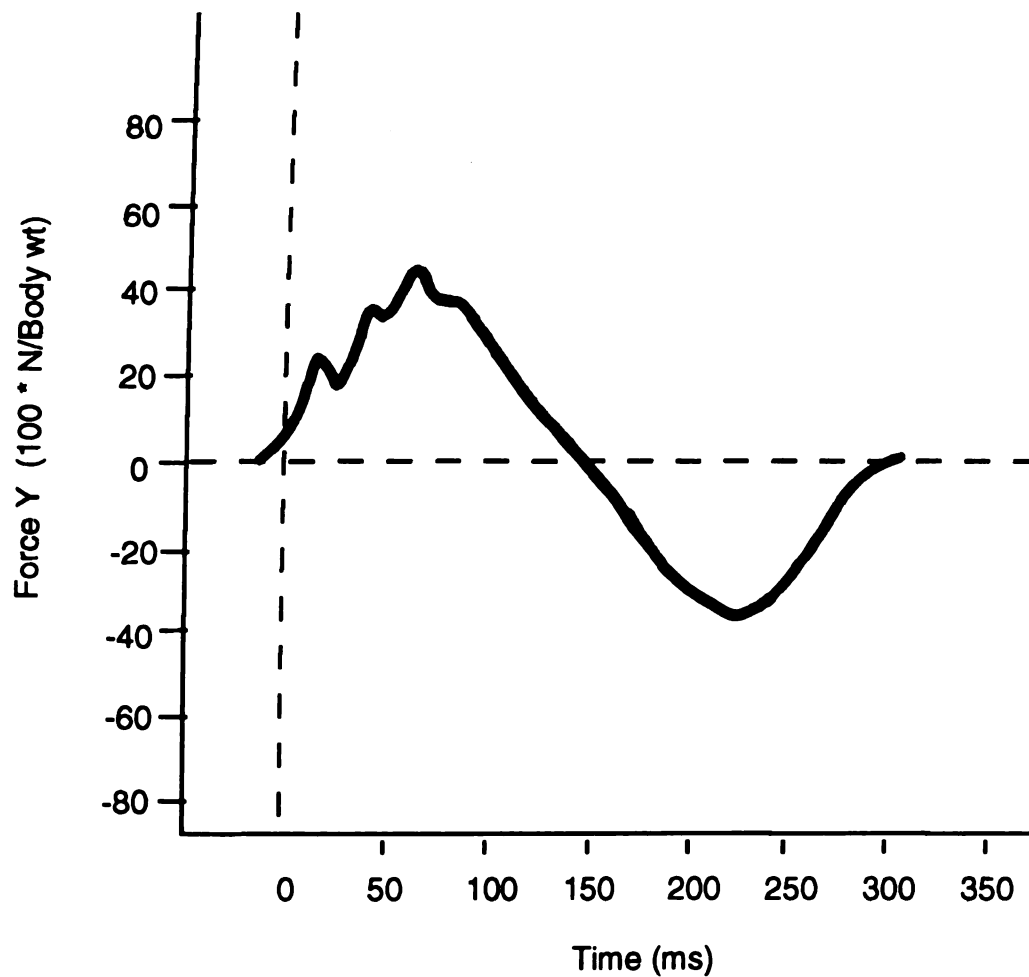


Figure 4.33b

This is a common anterior-posterior force experience of the nondominant leg of a subject in the group of recreational runners who were blind. The dominant foot, in most cases, produced high propulsive forces over longer periods of time. The nondominant leg experienced high braking forces and produced lower propulsive forces.

maintained comparable across the other subjects because propulsive force was applied over a longer period of time. Consequently, the level of efficiency on producing propulsive and generating braking forces was almost similar between the two groups of recreational runners who were blind. The fact that the forward speed was related to the force and the time that this force was applied, pointed to the need to examine the propulsive and braking impulses.

The anterior-posterior loading experiences of the subjects in the SB subgroup resembled the performance of the recreational runners who were blind (see Table 4.12). However, the relative time that the events after the peak braking force occurred was longer indicating that when the sighted runners ran blindfolded, they were less efficient than the recreational runners who were blind.

Braking and Propulsive Impulses

The results of the braking and propulsive impulses showed that the braking impulse was greater than the propulsive one in the nondominant leg, and the propulsive impulse was greater than the braking one in the dominant leg for the subjects in the BA and SB subgroups. The opposite was true for the subjects in the BB subgroup. However, this suggests that for individuals who might fall in the BA subgroup greatest propulsion is more likely to be produced by the dominant leg, whereas greatest brake is more likely to be experienced by the nondominant leg. The opposite is likely to happen for individuals that might fall in the BB subgroup.

This inter-relationship of the dominant and nondominant leg assisted each subject to maintain a similar total braking and propulsive impulse in order for a constant speed to be maintained (see Figure 4.34a, 4.34b). However, the different functions of the dominant and nondominant leg

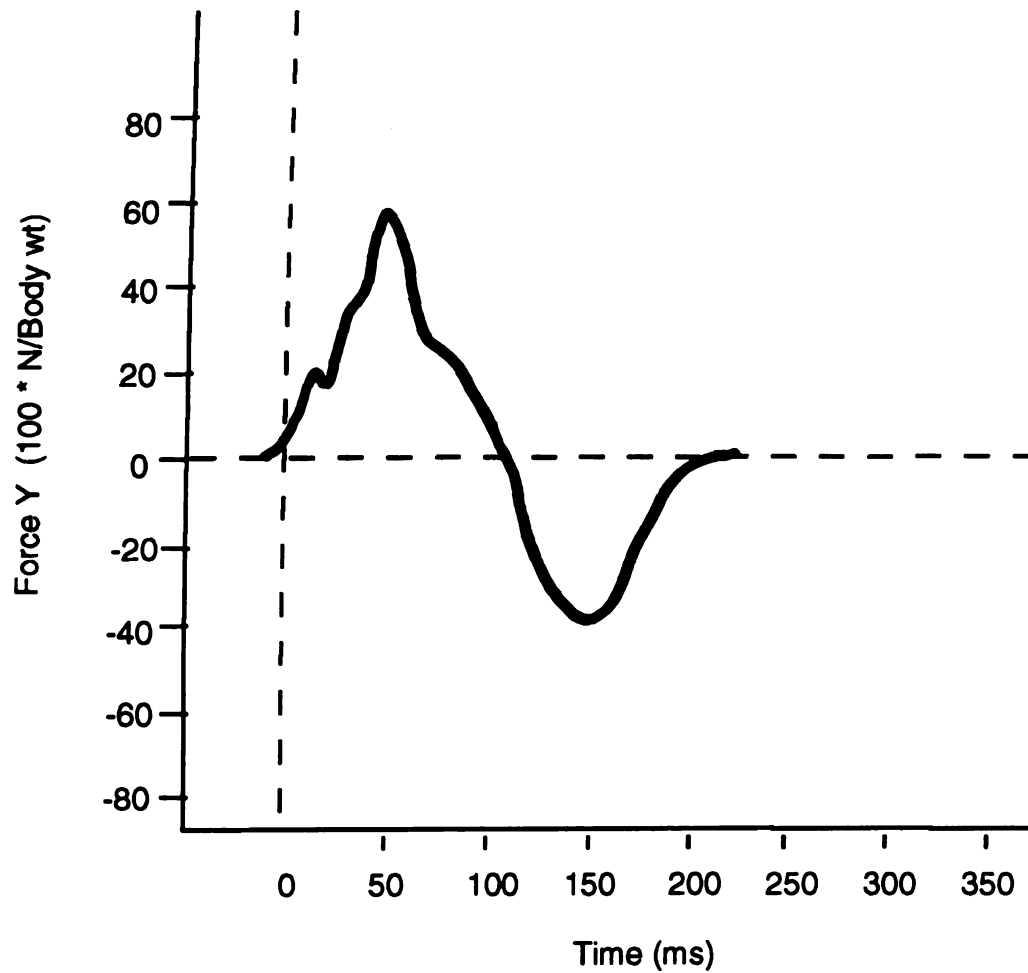


Figure 4.34a

The inter-relationship of the dominant and nondominant leg assisted each subject to maintain a similar total braking and propulsive impulse in order for a constant speed to be maintained. Here the loading experience of the nondominant leg of a subject in the BA subgroup is presented.

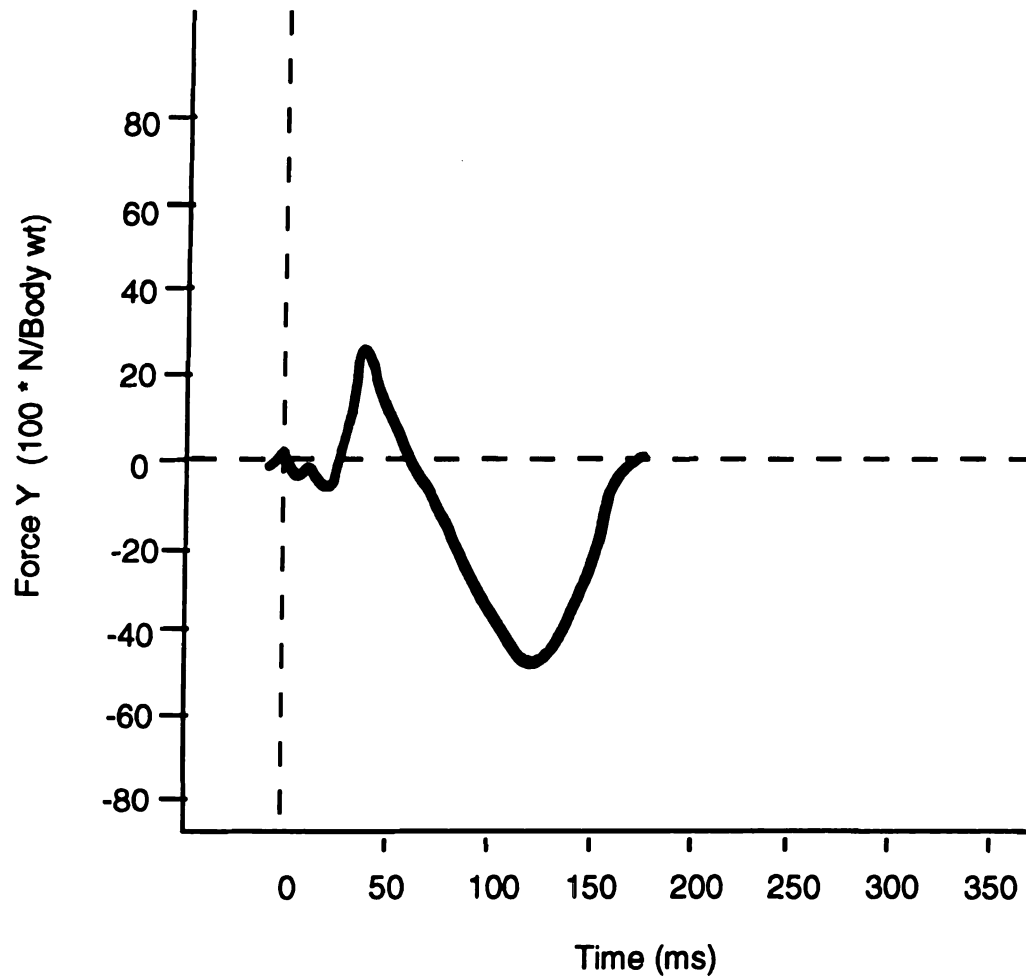


Figure 4.34b

The inter-relationship of the dominant and nondominant leg assisted each subject to maintain a similar total braking and propulsive impulse in order for a constant speed to be maintained. Here the loading experience of the dominant leg of a subject in the BA subgroup is presented.

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suggested asymmetries. According to Fisher and Gullickson (1978), the human body has been developed kinetically to decrease energy expenditure during ambulation and to minimize the metabolic cost with symmetry between the kinematic, kinetic, and temporal variables of the lower limbs. Because of the asymmetries that developed as a result of the visual characteristic or due to the assistive device, recreational runners who were blind appeared to be less efficient compared to the sighted runners. This agrees and can be related with the findings of Kobberling, Jankowski, and Leger (1989) who studied the energy cost of locomotion in blind adolescents and concluded that the energy costs of walking and running were highest among the totally blind subjects and decreased toward normal as a function of residual vision among the legally blind subjects. In addition, they found that the energy costs of walking and running were higher for blind adolescents than their sighted controls and their norm values.

In order to make comparisons among the subject subgroups the braking and propulsive impulses in Newtons were normalized across subjects by taking the ratio of the impulse of each phase to the impulse of the individual's body weight for the specific part of the stance phase. This was more accurate than the approach by Munro et al. (1987) who took the impulse of the individual's body weight for the entire stance phase. The results for the dominant and the nondominant leg are presented in Table 4.17.

Both groups, when impulses were normalized, appeared to have comparable ranges of normalized braking impulses for the dominant leg regardless of the age at onset of blindness. In most trials, the subjects in the BA subgroup appeared to perform better in generating propulsive impulses with the dominant leg and nondominant leg than the subjects in

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the BB subgroup. As was concluded earlier, high propulsive impulses produced by one leg were followed by high decelerating impulses experienced by the other leg. The subjects in the BA subgroup experienced the greatest braking impulses. Overall, the subjects in the BA subgroup, relative to the subjects in the BB subgroup, could generate more propulsion with both legs, they experienced greater resistance to propulsion with their nondominant leg, but they experienced comparable resistance to propulsion with the dominant leg. Therefore, the subjects in the BA subgroup appear to be more efficient than their counterparts in the loading experiences of the anterior-posterior component of the ground reaction force.

Table 4.17

Ratio of impulse to body weight impulse during the braking and propulsive phases of the stance phase for six trials.

Subjects	Dominant Leg		Nondominant Leg	
	Brake	Propulsion	Brake	Propulsion
BB1	0.08 - 0.18 (0.10)*	0.10 - 0.13 (0.10)	0.11 - 0.19 (0.15)	0.06 - 0.13 (0.11)
BB2	0.19 - 0.24 (0.22)	0.09 - 0.18 (0.10)	0.08 - 0.15 (0.10)	0.15 - 0.19 (0.16)
BA1	0.07 - 0.22 (0.14)	0.23 - 0.34 (0.23)	0.14 - 0.19 (0.16)	0.19 - 0.26 (0.26)
BA2	0.12 - 0.19 (0.13)	0.28 - 0.29 (0.28)	0.23 - 0.27 (0.23)	0.16 - 0.23 (0.16)
BA3	0.07 - 0.12 (0.12)	0.19 - 0.25 (0.20)	0.20 - 0.25 (0.24)	0.13 - 0.18 (0.15)

* = Median values are in parentheses.

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

The present study did not determine if the asymmetries were the result of the assistive device, or due to the visual characteristic. It appears that it is probably the combined effect of both.

Medio-lateral Ground Reaction Force

For the medio-lateral component of the ground reaction force, subjects demonstrated extreme variability. It has been stated that in the medio-lateral force the subjects express their individuality (Cavanagh, 1981). The results of the present study showed that the peak values of the medio-lateral force are relatively small compared to those of the anterior-posterior or vertical components of the GRF. The amplitudes reported in the present study agreed with those reported in the literature for sighted runners (Bates et al., 1983; Cavanagh & Lafortune, 1980; Hamill et al., 1983; Munro et al., 1987). The results of the present study did not indicate that there were double medial and double lateral peaks (Cavanagh & Lafortune, 1980). Most subjects in this study started laterally at foot strike, progressed medially, and ended laterally at toe-off.

Hypothesis 7

7. The kinetic and kinematic patterns of sighted recreational runners will be less efficient when they use a guide cable, than when they run without one (S).

The present study could not determine the effect of the guide cable in the running gait. In general, however, under the conditions of the study, the guide cable provided a more controlled form of running. As a result, the ranges of performance in selected variables were narrower. The pattern of the forces as well as their values became more consistent. In addition, the use of the guide cable increased the stance phase time. The negative inclination of the head demonstrated by the two subjects who were sighted

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guide cable. Examination of the force data for the vertical component when running with the use of the guide cable, revealed that there were no asymmetries in each of the two sighted subjects and that they were very consistent with their performances. Consequently, asymmetries demonstrated when the sighted subjects ran under the SB running condition can be attributed to the dependence of their stronger side as a result of visual loss.

CHAPTER V

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

Summary

The purpose of this project was to study selected kinetic and kinematic variables of the recreational runners who were blind, the effect of the age at onset on these variables, and the effect of a guide cable on the running technique. The kinematic variables included position data for the ankle, knee, hip, trunk, shoulder, neck, and head. The kinetic data, which were collected with a force platform, included vertical, anterior-posterior, and medio-lateral forces. A comparison was made between the results obtained in this study with the results obtained from investigations of the running gait of recreational runners who were sighted.

The subjects for this study were seven adult male recreational runners. Two of the subjects, 42 and 38 years of age, were blind and had lost their sight before five years of age (BB); three subjects, aged 37, 38, and 47 years, were blind and had lost their sight after the age of five (BA); and two subjects, aged 36 and 38 years, were sighted (S). Except for one individual, all the subjects had some competitive experience in long distance running in the past. Currently, they run between 8 and 16 km each week. The data collection consisted of two visits of each subject to the Center for the Study of Human Performance at Michigan State University. During the first visit, the subjects familiarized themselves with the laboratory area and activity history information was collected.

Anthropometric, kinematic, and kinetic data were collected during the second visit. The subjects ran on a motorized treadmill to warm-up and in order for the investigator to set a metronome to their pace. The preparation included placing body markers on the right side of their bodies (side of the head directly superior to the corner of the jaw near the vertex, angle of the jaw, level of the seventh cervical vertebra and in line with the markers on the superior side of the head and angle of the jaw, at the center of the neck, tip of the shoulder, greater trochanter of the femur, center of the knee joint, lateral malleolus of the ankle, and lateral metatarsals) as reference points for digitizing.

Following the practice trials, the subjects were asked to run naturally along a runway which included a force platform that was flush with the floor. The subjects who were blind ran holding on to a rope. The rope was attached to a baton through which a guide cable was placed. The guide cable was positioned on the subjects' right side, approximately at hip height to assist them to run in a straight line. The subjects who were sighted ran under three conditions: naturally (S), i.e., sighted, with the use of the guide cable (SC), and blindfolded with the use of the guide rope (SB). Five trials were filmed to collect kinematic information using one LOCAM 16 mm pin registration motion picture camera positioned with the optic axis of its lens perpendicular to the plane of movement. The camera was set at 100 fps and the filming speed was calibrated from timing lights placed in the field of view.

The kinematic data were collected after projecting the film onto a drafting table by a Vanguard Motion Analyzer and digitized

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using a Sonic Graf/Pen system. The digitizing system was interfaced with an IBM-PC, which was needed to collect the X and Y coordinates in a data acquisition computer program. A FORTRAN Bioanalysis program, developed at Michigan State University, was used to analyze the kinematic data.

The kinetic data were collected by an AMTI OR-6 Dynamometer connected on line with an IBM 9000 dedicated computer and were printed in graphs. Six successful trials were recorded, three for each leg, and analyzed.

Summary of Findings

Kinematics

The testing speed varied across all subjects. The target testing velocity was 3.5 m/s, but the subjects performed within a range from 2.41 m/s to 3.84 m/s. The reason for this was primarily the limited distance between the starting point and the filming area, which included the force platform. The subjects who were blind and blindfolded performed, in general, at a lower speed than the subjects who were sighted. They appeared to use the metronome as a reference to perform at their own velocity. The sighted subjects were found to undergo acceleration when they were in the camera's field of view and on the force platform. The lower speed demonstrated by the runners who were blind, or by the sighted runners when blindfolded, may have been the result of using different running techniques. This might be related to the visual condition and/or to the assistive device used. The difference in

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The sighted subjects accelerated during the testing when they ran under the S, and the SC conditions. These results have validity only for a person who accelerates. However, general qualitative conclusions could be drawn on the basis that, under both conditions, they were accelerating and the range of speed was approximately the same.

Presentation of the results for the runners who were blind in terms of dominant and nondominant legs appeared to be a more meaningful approach than presentation in terms of right and left legs. For each subject who was blind, one leg was experiencing a shorter support phase which led to the definition of the dominant and nondominant legs (see Chapter I). In the case of the subjects in the BA subgroup, the dominant leg was usually responsible for the high accelerating and propulsive forces generated. The nondominant leg was usually experiencing higher decelerating and braking forces. The opposite was true for the subjects in the BB subgroup.

The stance phase of the recreational runners who were blind was longer than the support phase of the sighted runners reported in the literature for comparable speeds. The stance phase of the subjects who were sighted in the present study was also shorter compared to the subjects who were blind. The stance phase of the sighted subjects who ran under the SC condition was also shorter than that of the runners who were blind, but longer than that of the subjects who ran under the S running condition.

Furthermore, the present study found that the subjects in the BB subgroup demonstrated longer support phases than the individuals in the BA subgroup who ran at comparable velocities. Also, it was

speculated that the dominant side was the side opposite to the one the individuals who were blind used to hold the person or device that was assisting them for their everyday ambulation.

The sighted individuals demonstrated longer airborne phases under all running conditions. All runners who were blind demonstrated airborne phases of comparable time periods. As a consequence, the stride lengths and cycle lengths of the sighted runners, at least when they ran under the S and SC conditions, were longer than those of the subjects in the blind group.

The cycle length of the subjects in the BB subgroup was shorter than all subject groups. The cycle length of the subjects in the BA subgroup was comparable to the cycle length of the sighted subjects when running under the SB condition.

The majority of recreational runners who were blind were midfoot strikers. At foot strike, all of the runners who were blind had the ankle of the support foot in a plantar flexed position which was followed by dorsi-flexion that was maximum immediately after mid-stance. Maximum dorsi-flexion was greater for the subjects in the BA subgroup compared to the dorsi-flexion of the subjects in the BB subgroup. Sighted runners have been reported to have greater maximum dorsi-flexion. At toe-off, plantar flexion was comparable for the two subgroups of recreational runners who were blind, but it was greater than what has been reported for sighted subjects running at similar velocities.

Knee flexion at foot strike and mid-stance was similar for the subjects in the group of runners who were blind. However, maximum knee flexion was less for the recreational runners who were blind

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compared to runners who were sighted. At toe-off, knee extension was a function of the subject's velocity and running technique.

Hip flexion at foot strike was similar for both groups of the runners who were blind. Hip flexion at foot strike reported in the literature for sighted runners, was also similar to the hip flexion angles demonstrated by the runners who were blind. After foot strike, hip flexion was followed by progressive extension until toe-off. In general, there was an interaction among the ranges of motion in the joints of the lower limb of the runners who were blind so that the desired speed could be maintained. Hip extension of the subjects in the group of recreational runners who were blind and in the group of the subjects who ran under the SB running condition, was, in general, smaller than the hip extension reported in the literature for sighted runners.

Trunk inclination at foot strike was negative for the recreational runners who were blind. From foot strike to toe-off, the trunk moved from negative to positive inclination. The sighted runners were reported in the literature to increase their inclination in the positive direction from foot strike to mid-stance. From mid-stance to toe-off, sighted runners were reported to decrease the trunk inclination to the same values they had at foot strike (Yoneda et al., 1979). In this study, the recreational runners who were blind either increased or maintained almost the same angle of trunk inclination, or increased it from mid-stance to toe-off.

The subjects in the BB subgroup increased the head and neck angle from foot strike to mid-stance and decreased it from mid-stance to toe-off. At the same time, they demonstrated negative

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inclination of the head at foot strike and during toe-off. The subjects in the BA subgroup maintained approximately the same head and neck angle from foot strike to mid-stance, and increased it from mid-stance to toe-off. Their head, however, tended to have positive inclination at foot strike. The positive head inclination was reversed to negative by mid-stance and toe-off. The subjects who ran under the SB running condition, tended to increase the head and neck angle progressively from foot strike to toe-off.

Flexion-extension at the shoulder joint was greatest for the S subjects. Shoulder flexion-extension was decreased for the sighted subjects when running under the SC condition, and it was decreased even more when they ran under the SB condition. Under the latter condition, the sighted individuals demonstrated slightly greater flexion-extension at the shoulder than the runners who were blind.

Kinetics

The recreational runners who were blind, although most of them were midfoot strikers, demonstrated force curves as if they were rearfoot strikers. When the sighted subject who was a midfoot striker ran blindfolded, he became a rearfoot striker and he demonstrated the initial impact peak force of maximum deceleration in the curve of the vertical component of the ground reaction force.

Maximum deceleration values were higher for the recreational runners who were blind compared to those experienced by the sighted runners reported in the literature. Maximum deceleration was also higher for the subjects in the BB subgroup, and it occurred in most trials within the first 28 ms of the stance phase.

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For similar speeds, maximum unloading values were higher for the recreational runners who were blind compared to those of the sighted runners reported in the literature. The maximum unloading values of the subjects in the BB subgroup were higher than those of the subjects in the BA subgroup. Maximum acceleration values were higher for the sighted runners, as they are reported in the literature, than for the runners who were blind in the present study. The rate of loading for most of the runners who were blind was within the norms reported for sighted recreational runners. However, when the BB and BA subgroups were compared, the subjects in the BB subgroup experienced higher rates of loading than the subjects in the BA subgroup for comparable running velocities.

The shape of the anterior-posterior force curves were biphasic, similar to that demonstrated by the sighted runners reported in the literature. The runners who were blind experienced higher braking forces than the sighted runners reported in the literature. The transition from the braking to the propulsive phase occurred earlier for the individuals who were blind and especially for the subjects in the BB subgroup. Peak propulsive forces were higher for the runners who were blind than for the sighted subjects, but occurred later in the stance phase. For the subjects in the BA subgroup, the dominant leg produced primarily high propulsive forces over long time periods. However, the opposite, in terms of leg dominance function, was true for the subjects in the BB subgroup.

The speed that was produced by each leg was proportional to the propulsive force and the time that this force was applied. Consequently, although the peak propulsive values were smaller for

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the subjects in the BB subgroup, the speed was maintained comparable across the other subjects.

The subjects who ran under the SB running condition had similar performance in the anterior-posterior component of the ground reaction force, as the subjects in the BA subgroup. However, after maximum braking, it took longer time for the other events of the stance phase to occur for the runners who ran blindfolded than for the subjects who were blind.

The braking impulse of the subjects in the BA subgroup, and of the subjects who ran under the SB running condition, was always greater than the propulsive impulse in the nondominant leg, and the opposite was true for the braking and propulsive impulses in the dominant leg. The reverse was true for the subjects in the BB subgroup.

After normalizing the data to make comparisons between the BA and BB subgroups, it was observed that all the subjects who were blind tended to have similar performances in the normalized braking impulse of the dominant leg. However, subjects in the BA subgroup performed better by generating a higher propulsive impulse relative to their body weight impulse with the dominant leg, but they also experienced greater braking forces with the nondominant leg.

A very high degree of individuality was found among subjects in the medio-lateral component of the ground reaction force with very small peak values. Most subjects in this study started laterally at foot strike, progressed medially, and ended laterally at toe-off.

The use of the guide cable forced the sighted subjects to perform a more controlled running. The stance phase was increased,

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and the subjects demonstrated a negative head inclination. No asymmetries were demonstrated for the sighted subjects when they ran under the S and SC running conditions.

Conclusions and Recommendations

The present study revealed that, in general, the recreational runners who were blind may be less efficient than the recreational runners who were sighted in positioning their bodies and generating forces to produce similar speeds. In addition, it was shown that the subjects in the BA subgroup generally had more efficient running technique than the subjects in the BB subgroup in positioning their bodies and generating forces to produce similar speeds. Therefore, age at onset of blindness appears to be a critical parameter. The effect of the guide cable on running technique could not be determined.

The recreational runners who were blind tended to bring their neck back and keep their head back which resulted in a postural adjustment bringing the trunk to an inclination negative from the vertical, opposite to the direction of movement. That poor running posture may have been the reason for experiencing greater retarding forces relative to the direction of movement. It can be speculated that during the support phase, that postural adjustment resulted in keeping the runner's center of gravity over the base of support for a longer period creating a more stable position. That period appeared to be longer for the subjects in the BB subgroup. However, because of the greater braking forces, the recreational runners who were blind had to apply greater propulsive forces in order to overcome the

greater retarding effect and maintain a constant speed. The result of this extra effort has been documented in the literature as greater energy expenditure on the part of the runners who are blind relative to the sighted individuals. It is absolutely essential, therefore, that those who teach running to individuals who are blind focus on correct running posture. Based on the results of this study, specific attention should be placed on the position of the neck and the head.

The poor posture was likely the reason for the longer stance phases and shorter stride and cycle lengths demonstrated by the runners who were blind. Keeping the neck back increased the relative time from deceleration to acceleration, and from braking to propulsion. The transition times were longer for the subjects in the BB subgroup. Also, in the case of the subjects in the BB subgroup, the shorter stride and cycle lengths could be the result of poor application of the resultant ground reaction force. One subject was accelerating upward more than forward. It may be, therefore, that the recreational runners whose age at onset was before five have difficulty associating the speed with the optimum application of force to achieve that speed.

The stance phase was increased with the use of the guide cable. The airborne phase of the sighted subjects appeared to be dependent on vision and the extent to which the subject had in his mind a frame of reference of the visual world and, therefore, was prepared to raise his center of gravity high off the supporting surface. Differences in speed were more likely to appear during the stance phase.

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Although the force graphs indicated that most runners who were blind were rearfoot strikers, poor posture may have been the reason that the majority of the runners who were blind demonstrated a midfoot foot strike. This may be an adaptation so that they will minimize the high ground reaction forces which were the result of their posture.

In addition, a training program for the recreational runners should be focused partly on teaching the runners to utilize more the range of movement in the joints, particularly for the runners who would fall under the BB subgroup. This is necessary so that efficient absorption of the ground reaction forces can take place during the support phase. Minimizing the decelerating and retarding ground reaction forces would decrease the likelihood of injury. Furthermore, ability to perform a wider range of motion in the joints, especially of the lower limb and in particular of the hip, would increase the propulsive forces at toe-off. In addition, ability to use the full range of motion of the hips allows greater "give" in movements that prevent exertion injuries of the pelvis and of the lower back. Furthermore, improving the ability to use the range of motion of the joints of the upper body is also of importance. Because the individuals who are blind use assistive devices for ambulation, the arm-leg opposition is confined. The angular momentum generated by the hip will have to be counteracted by the rotation of the upper body. In addition, coaches and teachers should try to identify methods to decrease contact of the individual with the assisting devices for running so that shoulder rotation can be increased.

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The recreational runners who were blind demonstrated a dominant and nondominant leg, each emphasizing different functions. For the BA and BB subgroups, the dominant leg was more involved in producing higher accelerating and propulsive forces, whereas the nondominant leg was more involved in experiencing the higher decelerating and braking forces. However, the opposite was true for the subjects in the BB subgroup. This observation points to the existence of asymmetries between the two legs, which usually result in greater energy expenditure. Leg dominance seemed to have developed over the years. It appeared to be inversely related to the side that the individuals were using the assistive device for everyday ambulation. The specialized personnel who teach the individuals who are blind mobility and orientation, might be able to teach them to use their assistive devices bilaterally during their everyday life.

In some instances, the performances of the subjects who ran under the SB condition resembled those of the recreational runners who were blind. In many instances the performances between the two sighted subjects were completely different so that no conclusions could be inferred. One subject appeared to be affected by the blindfolded condition, whereas the other seemed to recruit his memory of the visual world and his performance remained in many aspects similar to when he ran sighted with the use of the guide cable. Therefore, it can be concluded that comparisons between the subjects who ran under the SB running condition and blind individuals are not meaningful. The individuals who are blind

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should have their own standards against which they should be compared.

Recommendations for Future Research

To the best of the investigator's knowledge, this study was the first one that has investigated kinetic and kinematic parameters of the recreational runners who are blind. Consequently, the results of this project need to be validated and established by further research that will examine the same parameters over a range of speeds, with more subjects and more trials.

The protocol that has been used in this study may need to be modified if the researcher wishes to investigate the running gait of individuals who are blind running at one particular speed. In the present study, the use of the metronome did not accomplish this objective.

If a researcher is going to do a similar study, the person should make sure that the runway is long enough, especially for the runners who are sighted, if a control group is to be used. An outdoor running track where force plates could be installed might be the most appropriate environment. In the present study, the runway was sufficient for the runners who were blind, but not for the runners who were sighted. The reason was that, as it has been found in the study too, the recreational runners who are blind have shorter stride and cycle length than the sighted runners. Therefore, although a short distance might be sufficient for the runners who are blind to reach the desired speed, the same is not necessarily true for the sighted individuals.

It would be interesting to test the recreational runners without any assistive devices or with the assistive device on the preferred side to observe the side dominance.

Also electromyographic data would be of great interest to investigate the effect of the poor posture on the muscular recruitment for balance. Data would be then available about the level of antagonistic contractions.

Research that would investigate the behavioral and psychological causes of the different patterns between the recreational runners who would fall in the BB or the BA subgroups could throw additional light, and could provide new avenues to improve the running performance of the individuals who are blind. It could also increase the number of persons with visual characteristics who engage in running.

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APPENDICES

APPENDIX A

INFORMATION LETTER AND INFORMED CONSENT

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APPENDIX A

RUNNING GAIT STUDY
Information Letter

Dear Sir,

I am Tasos Karakostas, a Master's degree student in the Department of Physical Education and Exercise Sciences at Michigan State University. I am aware that you already have been contacted by telephone about a research project involving recreational runners and that you have indicated a willingness to participate as a subject in this study. The purpose of this letter is to inform you about this study in a more formal way.

In this study I will investigate the running patterns of recreational runners who are blind as well as those of individuals who are sighted. More specifically, body movement patterns as well as the range of forces experienced by the runners when their foot contacts a force plate while running will be studied. In addition, the effect of a guide cable on running technique will be studied. Furthermore, the effect of age at onset of blindness on the running patterns displayed will be examined.

Kinetic and kinematic information about gait patterns is very important for the athlete, coach, physical educator, and recreator. With this information, certain conclusions can be drawn about the running technique used by individuals. Consequently, suggestions can be made to improve running technique, which may result in improved performance while at the same time reducing the likelihood of injury.

In order for this study to be conducted, we need to arrange two times for you to come to the Center for the Study of Human Performance (CSHP) at Michigan State University. During the first visit, you will have the opportunity to become familiar with the laboratory environment and to practice, if you wish, for the data collection. At the end of the visit, some information regarding your running history as well as the degree, cause, and age at onset of your blindness will be recorded. It will be extremely helpful and appreciated if you can provide us with a physician's report to verify the degree of your blindness.

The second time you visit, we will collect the data. When you come to the laboratory we will record your age, height, weight, and your lower limb length. In order to collect information about your body movements while running, harmless, self-adhesive circular discs 1.5cm (3/4 inch) in diameter will be positioned on specific joints of your body. Then, you will warm up on a treadmill for three to five minutes until a comfortable running speed of 3.5 meters/second (8 minutes a mile) is attained. While on the treadmill, you will be spotted by two assistants, one behind you and one to your side.

After the warm up, data will be collected while you run on a runway at a speed of 3.5 meters/second and step on a force plate in the runway. Each trial will be filmed to collect information about your body motion. The force plate will send information to a computer about the forces exerted on your foot at the time it is in contact with the plate.

A metronome/beeper will be placed beyond the force plate to help you maintain your pace, and to let you know when you have passed the force plate so that you can slow down. A spotter positioned at the end of the runway will let you know, verbally, when you have run past the force plate. A cable, threaded through a track baton, will be suspended at approximately hip height on your right side. When you run, you will hold a short rope attached to the baton which will allow you to swing your arm naturally. The cable will help you to run in a straight line, and it will increase the chances of your foot hitting the force plate naturally after a few practice trials.

For comparative purposes, the two individuals who are sighted will run under three different conditions: a) without the guide cable, b) with the guide cable, and c) with the guide cable, but blindfolded. The procedures for data collection will be the same for all the subjects. The data collection time should not exceed one hour. Based on our pilot study, total testing time should not exceed two hours.

On both the orientation and data collection days, you can come to the laboratory dressed in your everyday clothing; however, in order to practice and to collect data, you will need to wear a pair of jogging shorts and a sleeveless T-shirt. Please make sure that the running shoes you will be wearing for practice and for data collection do not contain any orthotics.

When the data have been collected and analyzed, I will be in touch with you to provide you with feedback about the results. When I contact you, we shall discuss the patterns of forces experienced by your feet as you run as well as the movement patterns you use.

If the results of this project are published, you will be referred to by subject number and not by name. Your name will not appear anywhere in the published project.

Thank you for your kind attention, and for your willingness to participate in this study. I will contact you soon. At that time, I will answer any additional questions that you might have regarding your participation in the study. I intend to set up dates that are convenient for you to come to the CSHP. If you consent to participate in this study, please sign the enclosed informed consent form and bring it with you on your first visit. Remember, any time you feel that you want to drop out of the study, you can do so.

Yours sincerely,

Tasos Karakostas.

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RUNNING GAIT STUDY
Informed Consent

The exercise test and measurement procedures to be used in the study of Tasos Karakostas have been explained to me. I agree to serve voluntarily as a subject in the research described. I understand that this research is being undertaken to further knowledge concerning the running gait of athletes who are blind.

I understand that some physical discomfort may be experienced and that no beneficial effects are guaranteed. I further understand that certain inherent risks, like orthopedic injuries, are associated with any test of biomechanical evaluation. These risks include, but are not limited to, spraining an ankle while running on the treadmill or on the runway. I understand every reasonable effort will be made to minimize these risks and that emergency procedures and trained personnel are available to deal with unusual situations that may arise.

I have had the opportunity to ask questions regarding the test and procedures to be used. Furthermore, I have been informed that I am free to withdraw my consent and to discontinue my participation at any time.

I understand that the film may be used for presentations and that results of the study may be used in scientific publications with my anonymity assured, that the data of individuals will be treated in strict confidence, and that my results will be made available to me upon request.

I understand that if I am injured as a result of my participation in this research project, Michigan State University will provide emergency medical care, if necessary, but these and any other medical expenses must be paid from my own health insurance program.

I consent to participate in this study: _____
(Your Signature)

I consent to the use of the film for presentations at professional meetings: _____
(Your Signature)

Date: _____

Investigator's Signature: _____ Date: _____

APPENDIX B

EQUIPMENT

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APPENDIX B

A force plate, AMTI OR-6 Dynamometer with dimensions 50.8 cm x 45.72 cm was connected on line with an IBM 9000 dedicated computer. The sampled data were changed to digital form by an analog-to-digital converter. The output was read at a frequency of 1000 Hz, and was recorded by six channels for Fx, Fy, Fz forces, and Mx, My, Mz moments and a time channel on an eight-inch floppy disk via an IBM 9000 dedicated computer. (The data for the moments were not used because they were not among the kinetic parameters investigated by the author.)

A treadmill was used for each subject's warm up. The treadmill was operated via an IBM computer. A Sanyo micro tape recorder was also used during the warm up to record the sound of the individual's pace at 3.5 m/s. A metronome which was used during the data collection was set from the recorded sound.

Self-adhesive circular discs, 1.5cm in diameter (3/4 inch), were placed at specific body land marks on each subject. A 16mm Locam high speed cinematographic camera filming at 100 fps was used to collect selected kinematic information. The subjects ran on a runway, approximately eighteen meters long (18.19 m).

A 2 m free standing GPM (Martin type) anthropometer was used to measure the standing heights and the lower limb lengths of the subjects. The weight of each subject to the nearest pound was obtained with a Fairbanks PEG 123B scale and then converted to kg.

A 16 mm Locam camera loaded with a 125 ASA Kodak Ektachrome film 7242 Tungsten set at F/stop 4.0 was used for filming at approximately 100 frames per second.

A Vanguard Motion Analyzer projecting the film onto a drafting table was used to collect the kinematic data. The film was digitized using a Sonic Graf/Pen system. The digitizing system was interfaced with an IBM-PC, which collected the X and Y coordinates in a data acquisition computer program. A FORTRAN Bioanalysis program, developed at Michigan State University, was used to analyze the kinematic data.

APPENDIX C

SUBJECT'S ACTIVITY HISTORY

APPENDIX C

Form for Obtaining Information about the Subject's Activity History

Subject #: _____

Date: _____

Part A

YRS MTHS

--	--

- 1) How long have you been involved in physical activities, beyond normal daily activities?

YRS MTHS

--	--

- 2) How long have you been involved in running?

YES NO

--	--

- 3) Have you ever received coaching or instruction in running?

YRS MTHS

--	--

If yes, how long?

- 4) Have you ever taken part in athletic competition where running was required as part of

YES NO

--	--

the competition or was used for training or warm-up purposes?

If yes, explain how running was used.

Part B

YRS MTHS

--	--

- 1) What was your age at the onset of blindness?

YES NO

--	--

- 2) Do you know the cause of your blindness?

If yes, please indicate the cause.

YES NO

--	--

- 3) Is the degree of your blindness classified as B1?

Thank you for your cooperation!!

APPENDIX D

DATA FORMS

APPENDIX D

DATA SUMMARY

Subject #:_____

Date:_____

Sex:_____

Standing Height:____(cm) Standing Height:____(cm) Sitting Height:____(cm)
 (with shoes) (no shoes)

Lower limb length:____(cm) Weight:____(kg) Stride length:____(cm)
 (LLL) (% height)_____
 (% LLL)_____

Foot tested:_____ Stance Phase Time:_____(ms)

GRFz Vertical

Trial	Maximum Deceleration		Mid-Stance		Maximum Acceleration	
	% BW	% SP	% BW	% SP	% BW	% SP
Range						

GRFy Antero-posterior

Trial	Maximum Brake		Cross Over		Maximum Propulsion	
	% BW	% SP	% BW	% SP	% BW	% SP
Range						

GRFx Medio-lateral

Trial	Maximum		Cross Over		Maximum	
	% BW	% SP	% BW	% SP	% BW	% SP
Range						

% BW = Percent Body Weight

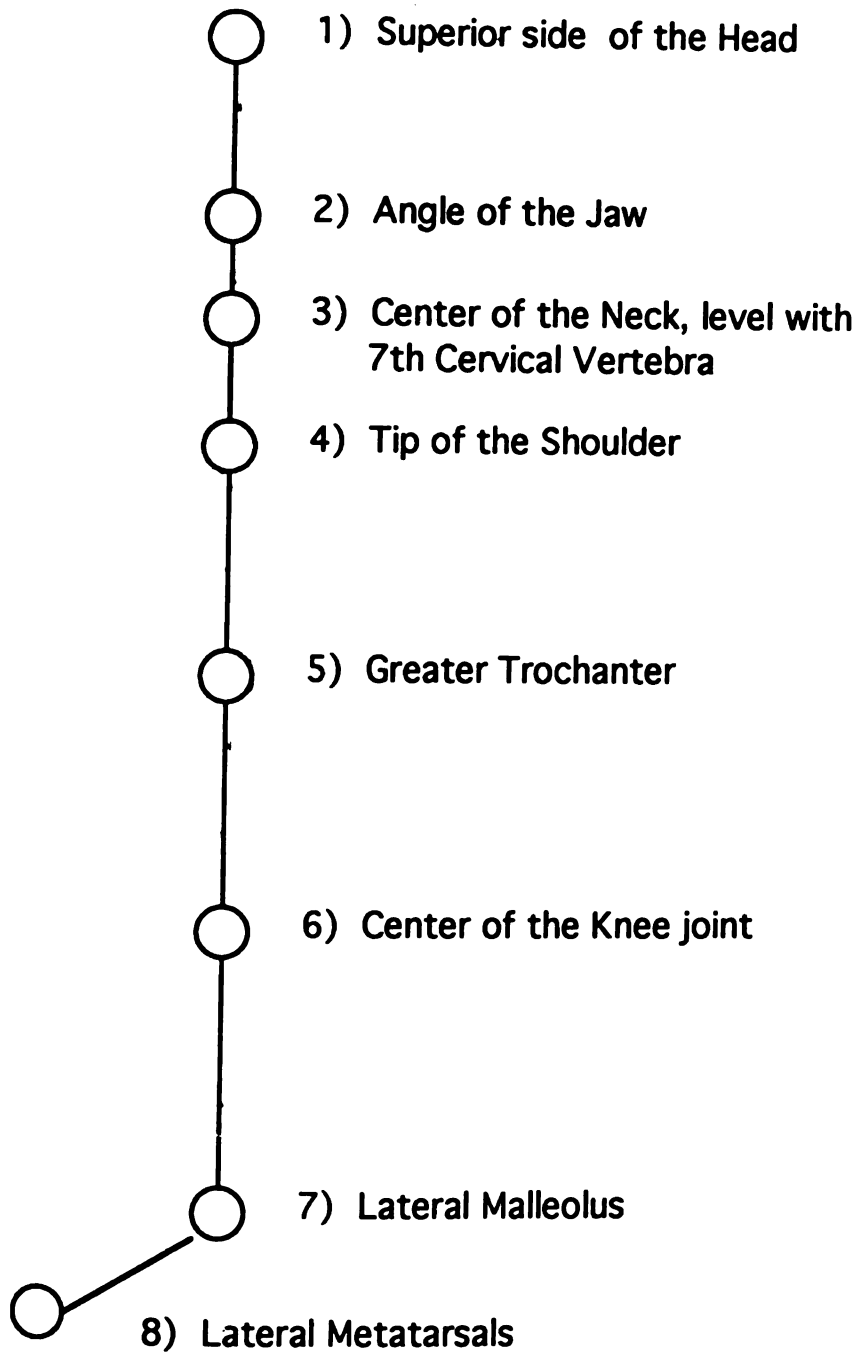
% SP = Percent Stance Phase

Parameter	Foot Strike	Mid-Stance	Toe-Off
Dorsi/Plantar flexion			
Knee angle			
Hip angle			
Trunk inclination			
Head-Neck angle			
Head inclination			

APPENDIX E

TARGETING PROTOCOL

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APPENDIX E



APPENDIX F

LABORATORY LAYOUT

APPENDIX F

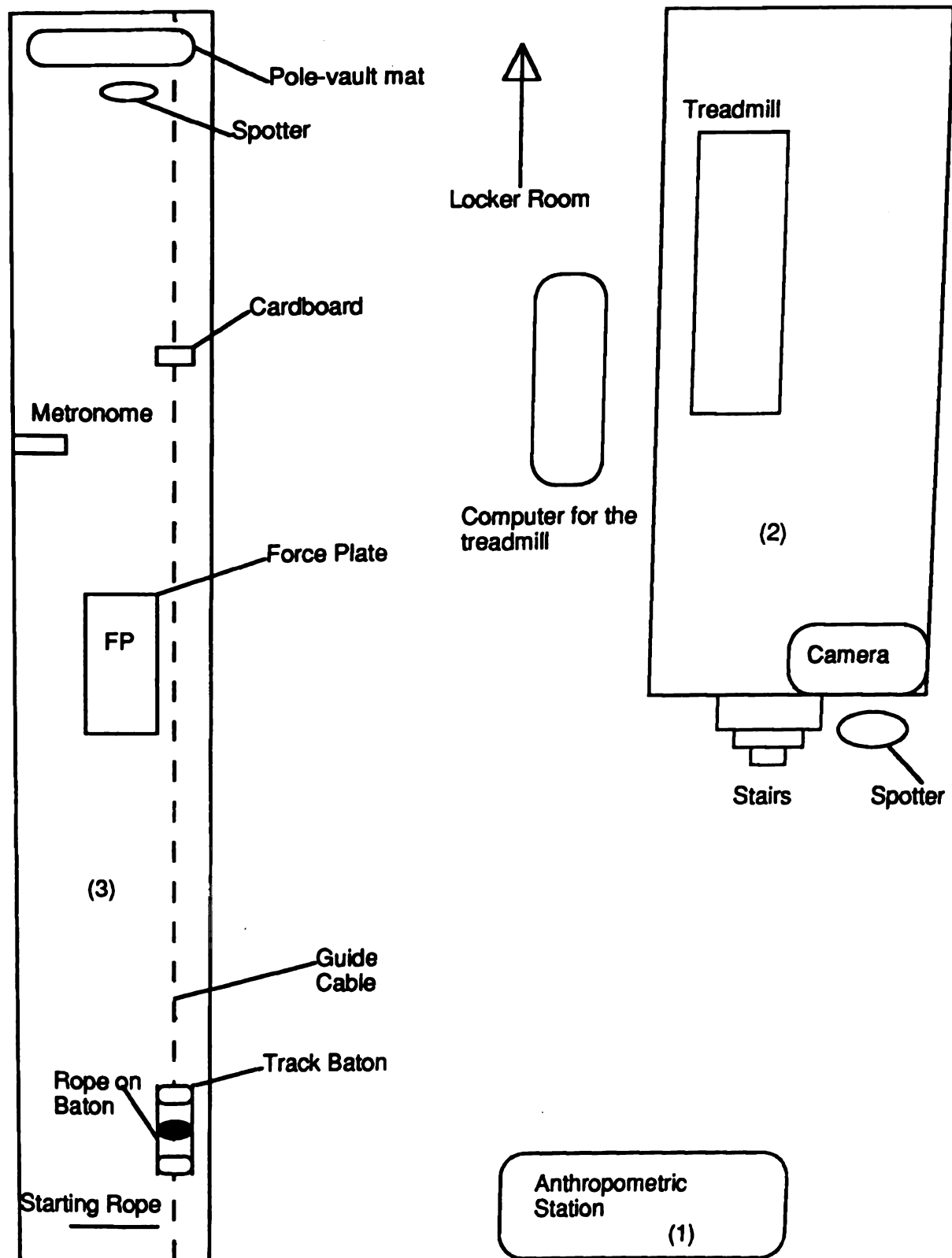


Figure 7.1
Layout of the laboratory area: 1) Anthropometric station, 2) Warm-up and Stride Frequency station, 3) Testing area. (The numbers indicate the sequence of activities and where these activities took place.)

APPENDIX G

PILOT STUDY

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APPENDIX G

One subject who was visually impaired (not totally blind) volunteered to assist with the establishment of a protocol for this study to be conducted in the Center for the Study of the Human Performance. The subject was an adult male, injury free, whose vision was at the range of 20/200, classified as "legally blind" (legally blind is the person whose central visual acuity does not exceed 20/200 in the better eye with correcting lenses, or whose visual acuity, if better than 20/200, has a limit in the central field of vision to such a degree that its widest diameter subtends an angle of no greater than twenty degrees - adopted by the American Medical Association). The subject was physically active and he was at the time the group leader of the visually impaired and blind on Michigan State University campus, which means that he associates with a large number and a variety of people who are blind. Thus, it was believed by the investigator that this subject could make suggestions about the way this project was planned. After trying out different ideas of the investigator, the subject provided feedback on what would be the best testing procedure in order to make the subjects feel comfortable and to insure success during the data collection.

The subject advised the investigator that individuals who are blind do not like dependence. They neither like to rely on others nor they like to be told what to do. Consequently, we concluded that the data collection procedure should be structured in such a way that would allow the subjects feel as independent as possible.

The subjects' warm up should be done on the treadmill. The warm up should start at a slow walking pace and progress to the desired for the study speed of 3.5 m/s and with at least one spotter at the side of the individual. The treadmill warm up would take care of adverse weather conditions that might occur outside the laboratory and it would show respect for their desire for independence. At the same time, during the final minute of the warm up, when the subject's pace is settled, we could set the metronome at the subject's individual pace.

The subject and the investigator also concluded, that the metronome should be placed on the left side of the runway past the force plate. That particular placement of the metronome should not interfere with the subject's running, and it should act as an indicator to the subject to let him know when he has passed the force plate. At the same time the metronome would allow the subject to maintain the predetermined desirable speed at his own pace. The subject and the investigator also concluded that a guide cable should be placed on the right side of the subject above the elbow level, with the forearm placed under the rope. The rope-arm placement will allow the provision of concurrent feedback to the subject so that he can run in a straight line. The cable should be in constant touch either with the subject's forearm or with the arm or with the trunk. This procedure should allow the individual to swing the arm in a natural fashion.

Another point the investigator and the subject in the pilot study agreed upon was that a rope should be taped on to the floor at the beginning of the runway to indicate the starting point. The rope

will provide tactile feedback to the subject's feet as to where the starting point is. In addition, during this pilot study we had placed a pole-vault mat at the end of the runway which, in case the subject had not slowed down, it would safely stop the subject. Furthermore, we decided that an assistant should be placed in front of the mat to remind the subject to slow down once he would ran past the metronome.

When three successful right footfalls were obtained by the subject of the pilot study , he was asked to change the starting leg so that he could perform another three successful left footfalls from the same starting point. However, this was not achieved. The conclusion was, and the subject suggested it too, that the subjects should always start with their natural starting leg and the starting mark should be adjusted to achieve another three successful trials with the other leg.

At the end of the session we checked if there was any effect on the subject's skin as a result of using the guide cable. There was no indication of any bruises or any other kind of damage on the subject's skin.

APPENDIX H

DATA OF INDIVIDUAL RUNNING VELOCITIES

Table 7.1
Individual data for running velocities.

Subjects	Velocity (m/s)
BB1	
Trial 1	2.45
Trial 2	3.80
Trial 3	2.64
Trial 4	2.53
Trial 5	2.41
BB2	
Trial 1	3.32
Trial 2	3.60
Trial 3	3.35
Trial 4	3.32
Trial 5	3.32
BA1	
Trial 1	2.86
Trial 2	2.78
Trial 3	2.77
Trial 4	2.82
Trial 5	2.95
BA2	
Trial 1	2.78
Trial 2	2.89
Trial 3	3.03
Trial 4	3.44
Trial 5	3.65
BA3	
Trial 1	3.84
Trial 2	3.06
Trial 3	3.91
Trial 4	3.05
Trial 5	3.80
S1	
Trial 1	3.52
Trial 2	3.74
Trial 3	3.74
Trial 4	3.81
Trial 5	3.75

Table 7.1 continued

Subjects	Velocity (m/s)
S2	
Trial 1	3.42
Trial 2	3.51
Trial 3	3.60
Trial 4	3.57
Trial 5	3.49
SC1	
Trial 1	3.42
Trial 2	3.39
Trial 3	3.43
Trial 4	3.46
Trial 5	3.72
SC2	
Trial 1	3.36
Trial 2	3.36
Trial 3	3.44
Trial 4	3.43
Trial 5	3.53
SB1	
Trial 1	3.14
Trial 2	3.29
Trial 3	3.11
Trial 4	3.05
Trial 5	3.04
SB2	
Trial 1	3.12
Trial 2	3.24
Trial 3	3.15
Trial 4	2.99
Trial 5	3.24

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

APPENDIX I

KINEMATIC DATA OF STANCE PHASES

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APPENDIX I

Table 7.2
Individual data of stance phases.

Subjects	Stance Phase (ms) Dominant leg	Stance Phase (ms) Nondominant leg
BB1		
Trial 1	245	241
Trial 2	233	249
Trial 3	232	243
BB2		
Trial 1	236	259
Trial 2	230	233
Trial 3	239	229
BA1		
Trial 1	242	298
Trial 2	271	292
Trial 3	283	289
BA2		
Trial 1	236	230
Trial 2	227	239
Trial 3	223	230
BA3		
Trial 1	191	214
Trial 2	180	219
Trial 3	200	209
Trial 4		202
S1		
Trial 1	208	213
Trial 2	226	213
Trial 3	205	231
S2		
Trial 1	178	231
Trial 2	194	206
Trial 3	212	204

Table 7.2 continued

Subjects	Stance Phase (ms) Dominant leg	Stance Phase (ms) Nondominant leg
SC1		
Trial 1	219	227
Trial 2	223	219
Trial 3	229	222
SC2		
Trial 1	204	222
Trial 2	223	229
Trial 3	220	236
SB1		
Trial 1	221	243
Trial 2	244	249
Trial 3	250	234
SB2		
Trial 1	244	253
Trial 2	241	257
Trial 3	245	257

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

APPENDIX J

KINEMATIC DATA FOR THE STRIDE AND CYCLE LENGTHS

APPENDIX J

Table 7.3
Kinematic data for the stride and cycle lengths.

Subjects	Stride Length				Cycle Length	
	First Stride		Second Stride		%SHS	%LLL
	%SHS	%LLL	%SHS	%LLL		
BB1						
Trial 1	47	96	48	95	95	191
Trial 2	47	96	48	95	95	191
Trial 3	41	84	42	86	83	170
Trial 4	44	90	47	93	91	183
Trial 5	44	90	47	93	91	183
BB2						
Trial 1	52	104	51	101	103	205
Trial 2	50	100	46	90	96	190
Trial 3	53	105	49	95	102	200
Trial 4	53	105	50	95	103	200
Trial 5	51	104	49	95	100	199
BA1						
Trial 1	53	107	63	127	116	234
Trial 2	48	98	61	123	109	221
Trial 3	55	112	57	115	112	227
Trial 4	59	119	58	117	117	236
Trial 5	52	109	65	132	117	241
BA2						
Trial 1	52	104	52	104	104	208
Trial 2	56	112	51	102	107	214
Trial 3	54	107	55	110	109	217
Trial 4	65	130	63	125	128	255
Trial 5	59	118	74	149	133	267
BA3						
Trial 1	59	118	86	161	145	279
Trial 2	63	127	64	129	127	256
Trial 3	60	120	60	120	120	240
Trial 4	58	117	60	120	118	237
Trial 5	61	122	60	119	121	241
S1						
Trial 1	64	127	76	150	140	277
Trial 2	65	128	72	143	137	271
Trial 3	65	128	76	151	141	279
Trial 4	65	128	77	156	142	284
Trial 5	69	136	73	144	142	280

Table 7.3 continued

Subjects	Stride Length				Cycle Length	
	First Stride		Second Stride		%SHS	%LLL
	%SHS	%LLL	%SHS	%LLL		
S2						
Trial 1	58	126	65	142	123	268
Trial 2	61	133	63	138	124	271
Trial 3	58	127	61	133	119	260
Trial 4	60	130	63	138	123	268
Trial 5	61	133	61	133	122	266
SC1						
Trial 1	62	124	68	136	130	260
Trial 2	66	132	66	132	132	264
Trial 3	63	126	69	137	132	263
Trial 4	60	119	68	134	128	260
Trial 5	62	123	67	134	129	262
SC2						
Trial 1	64	139	64	139	128	278
Trial 2	61	133	65	142	126	275
Trial 3	62	136	71	155	133	291
Trial 4	57	125	67	146	124	271
Trial 5	64	139	71	155	135	292
SB1						
Trial 1	59	118	62	124	121	242
Trial 2	65	131	64	129	129	260
Trial 3	60	125	61	121	121	246
Trial 4	59	122	58	113	117	235
Trial 5	61	121	60	119	121	240
SB2						
Trial 1	60	131	66	145	126	276
Trial 2	64	140	65	143	129	283
Trial 3	60	132	67	147	127	279
Trial 4	63	138	65	143	128	281
Trial 5	65	144	69	152	134	296

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

APPENDIX K

KINEMATIC DATA FOR THE ANKLE

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S

B

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APPENDIX K

Table 7.4

Kinematic data for the ankle at foot strike, mid-stance, and toe-off.

Subjects	Ankle (angles in degrees)		
	Foot Strike	Mid-stance	Toe-off
BB1			
Trial 1	132	98	133
Trial 2	124	93	123
Trial 3	128	93	130
Trial 4	125	98	130
Trial 5	127	91	138
BB2			
Trial 1	99	90	112
Trial 2	100	91	112
Trial 3	100	89	108
Trial 4	99	90	110
Trial 5	99	91	112
BA1			
Trial 1	124	94	132
Trial 2	125	91	142
Trial 3	101	92	139
Trial 4	83	91	140
Trial 5	118	87	141
BA2			
Trial 1	113	91	137
Trial 2	125	90	129
Trial 3	124	90	139
Trial 4	127	91	123
Trial 5	128	94	131
BA3			
Trial 1	107	95	140
Trial 2	110	93	143
Trial 3	106	92	145
Trial 4	107	97	146
Trial 5	108	97	145
S1			
Trial 1	95	88	112
Trial 2	89	86	116
Trial 3	86	91	112
Trial 4	91	87	127
Trial 5	89	86	119

Table 7.4 continued

Subjects	Ankle (angles in degrees)		
	Foot Strike	Mid-stance	Toe-off
S2			
Trial 1	106	90	137
Trial 2	112	94	133
Trial 3	114	94	144
Trial 4	111	91	134
Trial 5	114	96	142
SC1			
Trial 1	88	86	116
Trial 2	93	85	129
Trial 3	93	89	111
Trial 4	88	87	117
Trial 5	87	85	114
SC2			
Trial 1	112	92	151
Trial 2	113	92	149
Trial 3	114	92	138
Trial 4	113	91	146
Trial 5	116	95	144
SB1			
Trial 1	86	91	115
Trial 2	85	91	112
Trial 3	83	90	109
Trial 4	86	89	118
Trial 5	86	89	110
SB2			
Trial 1	105	93	138
Trial 2	106	89	138
Trial 3	105	90	136
Trial 4	104	89	142
Trial 5	104	90	138

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

APPENDIX L

KINEMATIC DATA FOR THE KNEE

APPENDIX L

Table 7.5

Kinematic data for the knee at foot strike, mid-stance, and toe-off.

Subjects	Knee (angles in degrees)		
	Foot Strike	Mid-stance	Toe-off
BB1			
Trial 1	160	145	176
Trial 2	158	151	175
Trial 3	155	146	179
Trial 4	155	150	178
Trial 5	155	142	176
BB2			
Trial 1	154	135	153
Trial 2	153	134	133
Trial 3	151	130	132
Trial 4	154	134	133
Trial 5	152	133	137
BA1			
Trial 1	150	135	159
Trial 2	150	134	162
Trial 3	159	134	159
Trial 4	128	133	158
Trial 5	138	132	160
BA2			
Trial 1	153	174	162
Trial 2	161	140	154
Trial 3	154	136	158
Trial 4	160	137	157
Trial 5	155	133	154
BA3			
Trial 1	159	130	166
Trial 2	160	141	172
Trial 3	158	132	171
Trial 4	161	142	170
Trial 5	160	141	172
S1			
Trial 1	128	139	151
Trial 2	122	145	160
Trial 3	126	140	154
Trial 4	127	141	157
Trial 5	131	147	161

Table 7.5 continued

Subjects	Knee (angles in degrees)		
	Foot Strike	Mid-stance	Toe-off
S2			
Trial 1	146	132	169
Trial 2	150	131	163
Trial 3	140	130	155
Trial 4	144	128	162
Trial 5	143	129	162
SC1			
Trial 1	134	139	128
Trial 2	152	133	155
Trial 3	158	139	151
Trial 4	157	139	153
Trial 5	151	137	150
SC2			
Trial 1	148	132	168
Trial 2	145	128	167
Trial 3	148	133	165
Trial 4	145	130	171
Trial 5	153	135	169
SB1			
Trial 1	147	135	148
Trial 2	139	134	148
Trial 3	146	130	141
Trial 4	144	127	141
Trial 5	148	135	144
SB2			
Trial 1	151	133	166
Trial 2	150	132	165
Trial 3	155	137	165
Trial 4	158	130	171
Trial 5	157	141	164

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

APPENDIX M

KINEMATIC DATA FOR THE HIP

APPENDIX M

Table 7.6

Kinematic data for the hip at foot strike, mid-stance, and toe-off.

Subjects	Hip (angles in degrees)		
	Foot Strike	Mid-stance	Toe-off
BB1			
Trial 1	157	158	191
Trial 2	158	162	193
Trial 3	158	163	212
Trial 4	157	152	187
Trial 5	151	152	187
BB2			
Trial 1	156	154	196
Trial 2	153	150	185
Trial 3	144	139	184
Trial 4	155	152	189
Trial 5	149	143	184
BA1			
Trial 1	139	162	187
Trial 2	140	162	190
Trial 3	141	163	194
Trial 4	133	154	186
Trial 5	129	159	186
BA2			
Trial 1	156	165	196
Trial 2	162	168	196
Trial 3	154	165	196
Trial 4	157	173	199
Trial 5	152	167	196
BA3			
Trial 1	155	150	189
Trial 2	155	160	192
Trial 3	159	157	194
Trial 4	162	166	194
Trial 5	160	160	194
S1			
Trial 1	122	157	171
Trial 2	119	156	170
Trial 3	118	154	172
Trial 4	116	154	170
Trial 5	124	155	175

Table 7.6 continued

Subjects	Hip (angles in degrees)		
	Foot Strike	Mid-stance	Toe-off
S2			
Trial 1	160	162	204
Trial 2	161	158	196
Trial 3	149	153	189
Trial 4	150	153	192
Trial 5	149	154	199
SC1			
Trial 1	133	163	177
Trial 2	146	158	180
Trial 3	147	161	173
Trial 4	133	162	178
Trial 5	133	161	173
SC2			
Trial 1	150	159	199
Trial 2	150	159	200
Trial 3	154	164	198
Trial 4	152	154	198
Trial 5	156	153	201
SB1			
Trial 1	136	163	180
Trial 2	133	164	180
Trial 3	134	154	171
Trial 4	135	160	179
Trial 5	138	157	173
SB2			
Trial 1	155	167	203
Trial 2	153	168	201
Trial 3	159	168	198
Trial 4	160	164	204
Trial 5	155	177	197

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

APPENDIX N

KINEMATIC DATA FOR THE INCLINATION OF THE TRUNK

APPENDIX N

Table 7.7

Kinematic data for the inclination of the trunk at foot strike, mid-stance, and toe-off.

Subjects	Trunk lean (angles in degrees)		
	Foot Strike	Mid-stance	Toe-off
BB1			
Trial 1	- 3	+11	+14
Trial 2	- 4	+11	+12
Trial 3	- 4	+11	+12
Trial 4	- 2	+13	+18
Trial 5	0	+14	+20
BB2			
Trial 1	- 4	+ 2	+ 7
Trial 2	- 3	+ 6	+ 2
Trial 3	+ 2	+10	+ 6
Trial 4	- 3	+ 7	+ 6
Trial 5	- 1	+ 4	+ 4
BA1			
Trial 1	+ 3	+21	+22
Trial 2	+ 2	+20	+22
Trial 3	+ 4	+17	+18
Trial 4	+ 6	+22	+23
Trial 5	+ 8	+22	+26
BA2			
Trial 1	- 4	+ 7	+ 9
Trial 2	- 8	+ 2	+ 5
Trial 3	- 5	+ 6	+10
Trial 4	- 8	+ 6	+10
Trial 5	- 5	+ 5	+ 8
BA3			
Trial 1	- 1	+ 8	+18
Trial 2	- 3	+ 9	+16
Trial 3	- 4	+ 8	+15
Trial 4	- 6	+ 7	+15
Trial 5	- 4	+ 9	+17
S1			
Trial 1	+20	+31	+32
Trial 2	+21	+37	+37
Trial 3	+22	+35	+34
Trial 4	+23	+35	+34
Trial 5	+21	+36	+35

Table 7.7 continued

Subjects	Trunk lean (angles in degrees)		
	Foot Strike	Mid-stance	Toe-off
S2			
Trial 1	-10	- 4	+ 9
Trial 2	- 7	+ 0	+12
Trial 3	+ 4	+10	+17
Trial 4	+ 3	+ 6	+14
Trial 5	+ 2	+ 6	+13
SC1			
Trial 1	+ 9	+22	+24
Trial 2	- 3	+27	+26
Trial 3	- 2	+27	+20
Trial 4	+ 8	+26	+26
Trial 5	+ 9	+25	+23
SC2			
Trial 1	- 2	+ 9	+15
Trial 2	- 4	+ 4	+13
Trial 3	- 5	+ 3	+10
Trial 4	- 5	+ 5	+15
Trial 5	- 7	+ 6	+12
SB1			
Trial 1	+ 5	+19	+21
Trial 2	+ 7	+19	+21
Trial 3	+ 5	+19	+20
Trial 4	+ 5	+16	+16
Trial 5	+ 4	+18	+17
SB2			
Trial 1	- 8	- 1	+ 7
Trial 2	- 9	0	+ 8
Trial 3	- 9	+ 1	+ 8
Trial 4	-10	- 2	+ 8
Trial 5	-10	+ 5	+10

BB = Recreational runner who is Blind and the age at onset was Before five.

BA = Recreational runner who is Blind and the age at onset was After five.

S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

APPENDIX O

KINEMATIC DATA FOR THE ANGLE BETWEEN THE HEAD AND THE NECK

APPENDIX O

Table 7.8

Kinematic data for the angle between the head and the neck at foot strike, mid-stance, and toe-off.

Subjects	Head and Neck (angles in degrees)		
	Foot Strike	Mid-stance	Toe-off
BB1			
Trial 1	157	160	159
Trial 2	158	161	168
Trial 3	159	167	165
Trial 4	157	152	157
Trial 5	155	161	158
BB2			
Trial 1	124	134	120
Trial 2	120	125	121
Trial 3	120	111	124
Trial 4	123	128	123
Trial 5	120	121	120
BA1			
Trial 1	163	165	178
Trial 2	154	158	164
Trial 3	117	122	133
Trial 4	125	127	125
Trial 5	124	125	142
BA2			
Trial 1	112	115	122
Trial 2	114	110	104
Trial 3	126	126	120
Trial 4	105	108	119
Trial 5	114	115	119
BA3			
Trial 1	139	143	132
Trial 2	132	128	120
Trial 3	135	139	142
Trial 4	128	139	141
Trial 5	136	140	141
S1			
Trial 1	154	140	159
Trial 2	140	144	161
Trial 3	150	144	155
Trial 4	154	144	152
Trial 5	138	149	153

Table 7.8 continued

Subjects	Head and Neck (angles in degrees)		
	Foot Strike	Mid-stance	Toe-off
S2			
Trial 1	148	152	161
Trial 2	150	155	152
Trial 3	153	167	168
Trial 4	148	152	161
Trial 5	151	161	154
SC1			
Trial 1	136	141	145
Trial 2	133	130	134
Trial 3	134	138	132
Trial 4	136	139	140
Trial 5	134	132	134
SC2			
Trial 1	114	122	123
Trial 2	131	128	131
Trial 3	128	133	139
Trial 4	120	131	130
Trial 5	129	136	134
SB1			
Trial 1	143	146	149
Trial 2	144	145	149
Trial 3	134	140	146
Trial 4	140	145	145
Trial 5	139	149	151
SB2			
Trial 1	134	132	139
Trial 2	126	136	140
Trial 3	129	133	135
Trial 4	129	131	135
Trial 5	127	130	134

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S = Recreational runner who is Sighted.

SC = Recreational runner who is Sighted, running with the use of the guide Cable.

SB = Recreational runner who is Sighted, running with the use of the guide cable, and Blindfolded.

APPENDIX P

KINEMATIC DATA FOR THE INCLINATION OF THE HEAD

APPENDIX P

Table 7.9

Kinematic data for the inclination of the head from the vertical at foot strike, mid-stance, and toe-off. Positive indicates inclination toward the direction of movement. Negative indicates inclination opposite to the direction of movement.

Subjects	Head inclination from the vertical (angles in degrees)		
	Foot strike	Mid-stance	Toe-off
BB1			
Trial 1	-15	-20	-21
Trial 2	-17	-21	-23
Trial 3	-16	-19	-18
Trial 4	-15	-20	-20
Trial 5	-13	-17	-18
BB2			
Trial 1	- 1	+ 3	- 8
Trial 2	- 7	-10	-16
Trial 3	+ 3	+ 2	0
Trial 4	- 4	+ 2	-10
Trial 5	- 1	0	- 6
BA1			
Trial 1	+ 7	+13	+ 2
Trial 2	+ 6	+ 3	+ 5
Trial 3	0	+ 2	+ 4
Trial 4	+ 7	+ 2	+ 4
Trial 5	+ 6	+ 1	+ 5
BA2			
Trial 1	- 5	- 9	- 4
Trial 2	- 5	- 7	- 4
Trial 3	- 4	- 6	- 7
Trial 4	-10	- 9	- 5
Trial 5	- 6	- 4	- 6
BA3			
Trial 1	+ 4	- 4	- 1
Trial 2	+ 4	- 1	- 3
Trial 3	+ 6	- 8	- 3
Trial 4	+ 5	0	- 2
Trial 5	+ 5	- 6	- 3
S1			
Trial 1	+17	+14	+21
Trial 2	+19	+13	+18
Trial 3	+25	+21	+27
Trial 4	+24	+17	+17
Trial 5	+16	+20	+15

Table 7.9 continued

Subjects	Head inclination from the vertical (angles in degrees)		
	Foot strike	Mid-stance	Toe-off
S2			
Trial	0	- 1	+ 1
Trial 2	0	- 1	- 4
Trial 3	+ 7	+ 8	+ 8
Trial 4	+ 4	+ 6	+ 5
Trial 5	+ 7	+ 5	+ 5
SC1			
Trial 1	- 4	- 7	- 7
Trial 2	- 3	- 7	- 4
Trial 3	0	+ 1	+ 1
Trial 4	- 3	- 7	- 6
Trial 5	- 3	- 5	- 4
SC2			
Trial 1	-21	-19	-18
Trial 2	-22	-23	-19
Trial 3	-17	-18	-17
Trial 4	-20	-19	-20
Trial 5	-22	-17	-19
SB1			
Trial 1	+14	+12	+14
Trial 2	+11	+ 8	+12
Trial 3	+ 6	+ 5	+ 4
Trial 4	+ 8	+ 6	+ 7
Trial 5	+17	+20	+22
SB2			
Trial 1	-13	-16	-12
Trial 2	-13	-17	-12
Trial 3	-10	-10	-10
Trial 4	- 9	-14	- 9
Trial 5	-15	-16	-15

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APPENDIX Q

KINEMATIC DATA FOR THE SHOULDER

APPENDIX Q

Table 7.10

Kinematic data for the shoulder at foot strike, mid-stance, and toe-off.

Subjects	Shoulder (angles in degrees)		
	Foot Strike	Mid-stance	Toe-off
BB1			
Trial 1	-39	-20	-15
Trial 2	-25	-18	- 3
Trial 3	-32	-17	-11
Trial 4	-34	-11	- 6
Trial 5	-25	- 6	+ 1
BB2			
Trial 1	+14	+21	+23
Trial 2	+ 3	+20	+21
Trial 3	+12	+23	+20
Trial 4	+13	+23	+22
Trial 5	+10	+21	+19
BA1			
Trial 1	- 2	+30	+32
Trial 2	- 2	+28	+26
Trial 3	-13	+ 9	+ 8
Trial 4	- 7	+16	+20
Trial 5	- 2	+21	+23
BA2			
Trial 1	-18	- 3	+ 2
Trial 2	-16	- 2	+ 4
Trial 3	-12	0	+ 4
Trial 4	-26	0	+ 2
Trial 5	-19	- 3	+ 2
BA3			
Trial 1	- 9	+17	+24
Trial 2	-10	+ 4	+12
Trial 3	- 9	+ 5	+15
Trial 4	-17	0	+13
Trial 5	- 9	+ 9	+17
S1			
Trial 1	-56	+25	+35
Trial 2	-62	+42	+52
Trial 3	-48	+34	+44
Trial 4	-40	+33	+45
Trial 5	-50	+40	+54

Table 7.10 continued

Subjects	Shoulder (angles in degrees)		
	Foot Strike	Mid-stance	Toe-off
S2			
Trial	-59	-36	+33
Trial 2	-48	-12	+51
Trial 3	-38	- 8	+40
Trial 4	-49	-11	+28
Trial 5	-43	-13	+25
SC1			
Trial 1	-35	-13	-11
Trial 2	-46	-15	-13
Trial 3	-41	-12	-10
Trial 4	-44	-15	-13
Trial 5	-40	-12	-11
SC2			
Trial 1	-35	-12	- 3
Trial 2	-38	-25	- 9
Trial 3	-37	-20	- 6
Trial 4	-36	-21	- 4
Trial 5	-36	-16	- 5
SB1			
Trial 1	-40	-18	-19
Trial 2	-38	-12	-12
Trial 3	-43	-20	-20
Trial 4	-35	-15	-17
Trial 5	-29	-14	0
SB2			
Trial 1	-13	0	+12
Trial 2	-23	- 6	+ 9
Trial 3	-31	-14	- 4
Trial 4	-48	-30	- 6
Trial 5	-24	+ 4	+12

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APPENDIX R

STANCE PHASES EXPRESSED AS PERCENT OF CYCLE LENGTH

APPENDIX R

Table 7.11

Kinematic data for the filmed individual stance phases expressed as percent of cycle length of each subject.

Subjects	Velocity (m/s)	Stance Phase as Percent of Cycle Length
BB1		
Trial 1	2.45	34.7
Trial 2	3.80	36.4
Trial 3	2.64	35.5
Trial 4	2.53	36.0
Trial 5	2.41	35.3
BB2		
Trial 1	3.32	36.3
Trial 2	3.60	38.4
Trial 3	3.35	36.1
Trial 4	3.32	36.3
Trial 5	3.32	37.2
BA1		
Trial 1	2.86	36.3
Trial 2	2.78	40.2
Trial 3	2.77	39.0
Trial 4	2.82	38.0
Trial 5	2.95	36.2
BA2		
Trial 1	2.78	37.2
Trial 2	2.89	37.0
Trial 3	3.03	34.9
Trial 4	3.44	33.6
Trial 5	3.65	36.1
BA3		
Trial 1	3.84	31.2
Trial 2	3.06	31.1
Trial 3	3.91	33.9
Trial 4	3.05	31.9
Trial 5	3.80	30.8
S1		
Trial 1	3.52	25.3
Trial 2	3.74	27.5
Trial 3	3.74	28.0
Trial 4	3.81	34.1
Trial 5	3.75	28.3

Table 7.11 continued

Subjects	Velocity (m/s)	Stance Phase as Percent of Cycle Length
S2		
Trial 1	3.42	27.8
Trial 2	3.51	29.3
Trial 3	3.60	30.0
Trial 4	3.57	28.4
Trial 5	3.49	26.3
SC1		
Trial 1	3.42	26.2
Trial 2	3.39	31.8
Trial 3	3.43	28.9
Trial 4	3.46	30.2
Trial 5	3.72	30.6
SC2		
Trial 1	3.36	32.5
Trial 2	3.36	30.8
Trial 3	3.44	30.0
Trial 4	3.43	30.8
Trial 5	3.53	29.0
SB1		
Trial 1	3.14	34.4
Trial 2	3.29	33.8
Trial 3	3.11	31.8
Trial 4	3.05	41.4
Trial 5	3.04	34.0
SB2		
Trial 1	3.12	34.1
Trial 2	3.24	34.0
Trial 3	3.15	34.1
Trial 4	2.99	34.0
Trial 5	3.24	34.1

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APPENDIX S

KINEMATIC DATA FOR AIRBORNE PHASES

APPENDIX S

Table 7.12
Kinematic data for the individual airborne phases.

Subjects	Airborne Phase (ms)	
	First Stride	Second Stride
BB1		
Trial 1	122	62
Trial 2	97	109
Trial 3	93	91
Trial 4	113	117
Trial 5	126	122
BB2		
Trial 1	83	122
Trial 2	94	94
Trial 3	72	93
Trial 4	101	95
Trial 5	82	134
BA1		
Trial 1	72	73
Trial 2	92	86
Trial 3	104	92
Trial 4	92	71
Trial 5	87	92
BA2		
Trial 1	84	83
Trial 2	90	92
Trial 3	86	92
Trial 4	103	94
Trial 5	85	114
BA3		
Trial 1	132	184
Trial 2	153	151
Trial 3	130	129
Trial 4	131	133
Trial 5	132	132
S1		
Trial 1	165	177
Trial 2	145	145
Trial 3	148	166
Trial 4	94	177
Trial 5	146	166

Table 7.12 continued

Subjects	Airborne Phase (ms)	
	First Stride	Second Stride
S2		
Trial 1	136	147
Trial 2	137	131
Trial 3	124	120
Trial 4	136	127
Trial 5	125	132
SC1		
Trial 1	166	185
Trial 2	146	133
Trial 3	143	155
Trial 4	124	145
Trial 5	126	123
SC2		
Trial 1	124	124
Trial 2	126	138
Trial 3	125	168
Trial 4	91	156
Trial 5	125	147
SB1		
Trial 1	125	154
Trial 2	156	135
Trial 3	135	145
Trial 4	157	114
Trial 5	145	164
SB2		
Trial 1	115	134
Trial 2	113	146
Trial 3	113	155
Trial 4	104	141
Trial 5	113	130

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APPENDIX T

**DATA FOR MAXIMUM DORSI-FLEXION AND MAXIMUM KNEE FLEXION
DURING THE SUPPORT PHASE**

APPENDIX T

Table 7.13

Kinematic data for the individual maximum dorsi-flexion, and maximum knee flexion of the support leg during the stance phase.

Subjects	Maximum Dorsi-Flexion	Maximum Knee Flexion
BB1		
Trial 1	76	144
Trial 2	77	146
Trial 3	73	145
Trial 4	74	147
Trial 5	78	142
BB2		
Trial 1	73	134
Trial 2	73	134
Trial 3	76	129
Trial 4	76	132
Trial 5	76	129
BA1		
Trial 1	86	124
Trial 2	82	121
Trial 3	79	120
Trial 4	78	123
Trial 5	83	120
BA2		
Trial 1	79	165
Trial 2	81	140
Trial 3	76	136
Trial 4	79	132
Trial 5	80	133
BA3		
Trial 1	79	130
Trial 2	80	132
Trial 3	80	130
Trial 4	79	141
Trial 5	81	138
S1		
Trial 1	72	115
Trial 2	73	122
Trial 3	73	120
Trial 4	77	121
Trial 5	75	120

Table 7.13 continued

Subjects	Maximum Dorsi-Flexion	Maximum Knee Flexion
S2		
Trial 1	72	132
Trial 2	68	131
Trial 3	72	128
Trial 4	75	128
Trial 5	74	129
SC1		
Trial 1	69	111
Trial 2	73	120
Trial 3	68	111
Trial 4	67	119
Trial 5	75	120
SC2		
Trial 1	81	131
Trial 2	73	127
Trial 3	71	128
Trial 4	80	130
Trial 5	79	135
SB1		
Trial 1	76	119
Trial 2	76	122
Trial 3	82	122
Trial 4	80	119
Trial 5	81	123
SB2		
Trial 1	79	133
Trial 2	80	131
Trial 3	77	137
Trial 4	80	130
Trial 5	75	131

Table 7.13 continued

BB = Recreational runner who is Blind and the age at onset was Before five.
 BA = Recreational runner who is Blind and the age at onset was After five.
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