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The purpose of this study was to examine pressure at five selected sites on the plantar surface of the foot and adaptations in running kinematics among fourteen male varsity collegiate distance runners on five different surfaces--asphalt, cinders, concrete, grass, and tartan. Pressure data were collected with an Electrodynogram system (EDG) and kinematic data were collected with a Redlake LOCAM 16mm high-speed camera operating at 100 fps. Repeated measures ANOVA was utilized to evaluate differences ($p<0.10$) among the variables. Pressure at the fifth metatarsal site on the left foot was found to be higher on the harder surfaces--asphalt, concrete, and tartan--than on the softer surfaces--grass and cinders. Higher pressures were found, in general, on the metatarsal region of the foot as opposed to the calcaneal region, especially while running on the harder surfaces. This finding may suggest that adequate shock absorption occurs

in the calcaneal region of the shoe used in this study, and/or the metatarsal region of the foot-shoe interface may merit more attention than is commonly thought. This contention is substantiated by the research of Cavanagh & LaFortune (1980). Among the kinematic variables quantified--stride length, stride rate, single leg support time, and swing time--only stride rate varied with surfaces. Stride rate was found to be slightly, but significantly ($p<0.10$) slower on concrete and asphalt than on the softer surfaces. The differences observed may be representative of a tendency of runners to slow down on concrete and therefore attenuate as much force as possible. This contention is substantiated by the research of Feehery (1986) and Nigg (1985). The other three kinematic variables were relatively unaffected by differences in the running surfaces investigated. The results of this study indicate that the underlying mechanisms and adaptations to running on different surface types are extremely complex phenomena which merit further investigation before physical educators and coaches can be provided with firm guidelines for appropriate running surface(s) for students and athletes.

The Effect of Surface Type on Plantar Pressure Distribution and Running Kinematics

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Table of Contents

List of Figures

List of Tables

List of Appendix Tables

Table		Page

THE EFFECT OF SURFACE TYPE ON PLANTAR PRESSURE DISTRIBUTION AND RUNNING KINEMATICS

CHAPTER I

INTRODUCTION

Running has been described as "essentially a series of collisions with the ground" (McMahon & Greene, 1979, p. 893). These "collisions" create forces during distance running that are 1.5 to 3 times larger than those present during walking (Cavanagh & LaFortune, 1980; Frederick & Hagy, 1986). The findings of Bates (1983) also indicate that for each mile run, the average runner encounters 450-550 "collisions" at 2-4 times his/her body weight as the foot impacts the running surface. Bates' conclusions are consistent with reports by Brody (1980) and by Dickinson, Cook, and Leinhardt (1985).

The "collisions" that are created at impact with the surface send shock waves throughout the human body. These waves create peak acceleration values ranging from 9g to 12g at the heel and from 11g to 15g at the forefoot of a running shoe (Frederick, Clarke, & Hamill, 1984).

The collisions of the foot and shoe with the surface (i.e. foot-shoe-surface interface) and the resulting shock waves commonly manifest themselves in running-related injuries. It is hardly surprising then that up to 70% of people who run (estimated to be approximately 20% of the general population (McKenzie, Taunton, & Clement, 1986) will at some time incur some type of running-related injury (Brody, 1980; Dickinson et al., 1985; Nigg, 1985).

To fully understand the etiology of running-related injuries Harrison, Lees, McCullagh, and Rowe (1987), pointed out the need to "examine the forces and how these change with the use of footwear, speed, fatigue, and the surface the runner encounters daily" (p. 860). Bates, Osternig, Sawhill, and James (1983) have also emphasized the paramount importance of studying the actions that occur at the foot-shoe-surface interface, since these actions influence the functional mechanisms of the entire body--especially the lower extremities. Cavanagh and LaFortune (1980) have further expounded on this need, stating that "If the etiology of these injuries (running-related) is to be fully understood it is clearly important to define the input conditions experienced by the musculoskeletal system each time the foot strikes the ground during the running cycle" (p. 397).

Several investigators have delved into the effects of shoes on shock absorption during running (Bates, Osternig, Sawhill, & James, 1983; Cook, Kester, & Brunet, 1985; Frederick, 1986; Komi, Gollhofer, Schmidtbleicher, & Frick, 1987; Luethi, Denoth, Kaelin, Stacoff, & Stuessi, 1987; Nigg, Bahlsen, Luethi, & Stokes, 1987; Norman, 1983; Snel, Delleman, Heerkens, & van Ingen Schenau, 1985; Valiant, McMahon, & Frederick, 1987). Likewise, a number of researchers have evaluated ground reaction forces during running using force platforms (Bates, 1983, Nigg et al., 1987; Cavanagh & LaFortune, 1980; Frederick & Hagy, 1986; Munro, Miller, & Fuglevand, 1987; Payne, 1983; Simon, Paul, Mansour, Munro, Abernathy, & Radin, 1981). In addition, skeletal shock transients and shock attenuation have received a fair amount of study (Dickinson et al., 1985; Light, McLellan, & Klenerman, 1980; Wosk & Voloshin, 1981).

Another factor related to the etiology of running-related injuries is the compliance of the running surface (Feehery, 1986). This is substantiated by James, Bates, and Osternig's (1978) statement that "Much long distance running is done on hard surfaces which provide little shock-absorbing capacity. Runners should be advised to run on a relatively soft surface such as a grassy area or on the soft shoulder of the road" (pp. 45-46). This same advice has been proposed by others (Brody, 1980; Butler, 1982; McKenzie, Clement, & Taunton, 1986; Nigg, 1985; Roy & Irvin, 1983; Subotnick, 1985). This advice has been based, however, on inferences from related studies and on data from injury reports. Very few studies have directly dealt with the nature of the surface a runner must encounter during his/her run. Three studies (Al-Hasso & Sawhill, 1988; Feehery, 1986; McMahon & Greene, 1979), have, indicated that softer surfaces may contribute to the prevention of running-related injuries. With a large percentage of the general population involved in running and the chances of incurring an injury so high (70%), it is crucial to understand the ways the runner can adapt to the surface that he or she must encounter. To date, most research has focused on the shoe and foot components of the shoe-foot-surface interface. Of equal importance may be the study of the surface; pilot data collected from three subjects indicate that experienced runners may minimize the impact forces to which they are subjected during running through kinematic adaptations to different surfaces. This phenomenon has also been documented by Feehery (1986), and Nigg (1985). If this is the case, an understanding of subtle kinematic adaptations could potentially contribute to a reduction in the incidence of running related injuries. The present study was designed to examine the effects of different surfaces on plantar pressure and running kinematics.

Statement of the Problem

The problem in this study was to examine pressure at selected sites on the plantar surface of the foot and adaptations in running kinematics among male varsity collegiate distance runners on five different surfaces. This information will provide physical educators and coaches with information regarding the contribution of surface hardness to running related injuries as well as contributing to the scientific knowledge base regarding the effects of running on different surfaces.

Research Hypotheses

The following are the research hypotheses for this study: (a) type of running surface (asphalt, cinders, concrete, grass, or tartan) affects the magnitude of the pressure present at the following sites on the plantar surface of the foot: hallux, first and fifth metatarsals, and medial and lateral calcaneal areas, (b) type of running surface (asphalt, cinders, concrete, grass, or tartan) affects the pressure distribution on the plantar surface of the foot, and (c) type of running surface (asphalt, cinders, concrete, grass or tartan) affects the following kinematic variables: stride length, stride rate, single leg support time, and swing time.

The following statistical hypotheses reflect the research hypotheses:

(a) Ho : $\beta i = 0$

H1 : $\beta i \neq 0$

--where Bi is any pairwise comparison among means for a given pressure site over the five surface types.

(b) Ho : $\gamma i = 0$

Hi : $\gamma i \neq 0$; where γi is a sensor x surface interaction contrast of interest.

(c) Ho : $\theta i = 0$

Hi : $\theta i \neq 0$; where θi is any pairwise comparison of means for a given kinematic variable over the five surface types.

Definitions

Pressure: Force divided by the area over which the force is distributed. Measured by the Langer Electrodynogram (EDG) system in units of kg/cm2.

Running kinematics: Temporal and spatial aspects of running; commonly referred to as "running form" or "technique." Kinematic variables examined include:

(a) stride length: the distance traveled between successive contact points of the same foot (Williams, 1985).

(b) stride rate: the inverse of stride time which is the time between successive contacts of opposite feet

(Williams, 1985).

(c) single leg support time: the time that a foot is in contact with the ground.

(d) swing time: time between successive ground contacts of one foot.

(e) speed: stride length multiplied by stride rate (Hay, 1985).

Surface hardness: Resistant to pressure; firm and unyielding; rigid; solid and compact (Guralnik, 1978).

Assumptions

It was assumed that the running shoes attenuated the impact forces to which the runners were subjected while running on the different surfaces. It was also assumed that the runners did not consciously attempt to modify running kinematics (style) on the different surfaces.

Limitations

A possible limitation to this study was the novelty of the electrodynogram for the subjects. Wearing the transducers may have caused minor modifications of gait, although the electrodynogram system utilizes wafer-thin pressure sensors which are designed to minimize this possibility.

A second possible limitation was that filming was done from a single camera view. There may have been asymmetrical movements on the other side of the body that would not be discernible. However, the single camera view has been found to provide data on running that are comparable to those derived from three-dimensional filming techniques (Williams, 1985).

Delimitations

The findings of this study are delimited to:

1. Competitive collegiate-level male distance runners.
2. The five surfaces studied--concrete, asphalt, cinders, grass, and tartan.

CHAPTER II

REVIEW OF LITERATURE

The review of literature for this study encompasses a review of running kinematics, ground reaction forces, pressure distribution, skeletal transients and shock attenuation, and finally, running surfaces.

Running Kinematics

In reviewing the research pertaining to running kinematics, Dillman (1975) pointed out that the most commonly quantified variables have been stride length and stride rate. This is in agreement with Atwater (1973) and with William's review of the biomechanics of running (1985).

Cavanagh and Williams (1985) focused on the relationship between stride length variation and the concomitant change in oxygen uptake. The major conclusion of this study was that there is a stride length that minimizes energy consumption, but that this optimal stride length varies from subject to subject. These authors again looked at the mechanics of running economy and performance in 1987 and found similar conclusions (Williams & Cavanagh).

Other researchers have examined the effects that stride length and stride rate have on running speed (Dillman, 1975; Elliott & Blanksby, 1979; Grillner, Halbertsma, Nilsson, & Thorstensson, 1979; Kaneko, Ito, Fuchomoto, Shishikura, & Toyooka, 1983; Kaneko, Matsumoto, Ito, & Fuchimoto, 1987; Luhtanen & Komi, 1978; Nilsson, Thorstensson, & Halbertsma, 1985; Williams, 1985; Winter & White, 1987). These authors found a curvilinear relationship between stride length and running speed. That is, as running speed increased, stride length increased up to a point, but that at the highest speeds stride length actually shortened (Luhtanen & Komi, 1978; Nilsson et al., 1985). Stride rate also increases with an increase in speed (Brandon & Boileau, 1987; Luhtanen & Komi, 1978; Nilsson et al., 1985). However, as Dillman (1975) pointed out, "when speed is held constant, as in distance running, 'better' runners have a lower stride frequency than 'poor' runners" (p. 205). It has also been shown that as the distance of the run increases there is a concomitant decrease in velocity and in stride length (Brandon & Boileau, 1987).

Speed also has an influence on the time of support. Williams (1985) pointed out that both the absolute and relative time spent in the support phase of the running cycle decreases as running speed increases.

This is in agreement with the findings of Grillner et al. (1979) and of Mann, Moran, and Dougherty (1986). It has also been shown that the time for the total running cycle decreases when running speed increases (Williams, 1985). Changes in joint angles during the stride cycle have also been studied. For example, maximal thigh angles during hip flexion have been found to occur just prior to foot strike (Nilsson et al., 1985; Williams, 1985). Nilsson et al. (1985) pointed out that hip flexion occurs primarily during the swing phase and hip extension primarily during the support phase. They also reported that knee flexion-extension movements occur during both the swing and support phases, and that in general, there is a decrease in the duration of both phases with increased running speed.

Ground Reaction Forces

In the introduction section the importance of understanding the etiology of running-related injuries was identified. Cavanagh and LaFortune (1980) have pointed out that this understanding is based on a sound knowledge of ground reaction forces, how these forces attenuate through the body, and how pressure is distributed throughout the foot-shoe-surface interface.

Cavanagh and LaFortune (1980) used a force platform to collect ground reaction force measurements from 17 runners. They found that vertical forces of between 1.5 and 3 times the body weight of a runner are commonly present at impact. These findings are consistent with those of other researchers (Bates et al., 1983; Frederick & Hagy, 1985; Kuntz & Terauds, 1983). They further reported that the magnitude of the peak vertical ground reaction force was highly variable among subjects. This indicated that some individuals experience less force than others while running at the same speed.

Frederick and Hagy (1985) found that with an increase in speed there is generally a concomitant increase in the peak ground reaction forces. They also reported an increase in ground reaction forces with increased body mass.

Payne (1983) compared walking, race walking, and running. Not surprisingly, his results were similar to those of Frederick and Hagy. Payne reported an increase in force amplitudes and a decrease in the time of application when locomotion speed increased. The initial force peaks observed during running were much larger and sharper upon initial contact with the ground than those found during walking or race walking.

Other studies evaluating ground reaction forces have been conducted in a clinical setting (Jansen & Jansen, 1978; Kljajic', Krajnik, & Stopar, 1985; Simon et al., 1981). Of particular relevance to the present study is the investigation by Simon et al. (1981). Using force transducers embedded in a shoe, these researchers found that a more compliant surface resulted in smaller frequencies at heel strike, a phenomenon which is indicative of a smaller load. They also found that by shifting to a crepe soled shoe or to a floor with a carpet, patients often gained relief from pain in the heel.

Pressure Distribution

It has been proposed that pressure distribution is an important factor to study relative to the understanding and prevention of injuries (Hennig & Cavanagh, 1987). This contention is further augmented by the statement, "To develop movements, sporting tools, shoes, and types of surfaces that reduce the possibility of injury, one needs to know the forces acting on the muscles, tendons, and joints" (Nicol & Hennig, 1978, p. 374). It is not convenient to directly measure the forces imparted to the joints in live human subjects. Therefore, indirect measurements such as pressure on the plantar surface of the foot are necessary. These measurements can then be used as a basis for inferences as to how forces are distributed and attenuated throughout the human body.

Cavanagh and Ae (1980) developed a technique for measuring pressure distribution that incorporates an array of transducers with a direct analog readout on an imaging graphics computer. The problem with this technique was that it was extremely laborious and costly. Also, it could only be used in a clinical setting where a large power source was available.

Another method was introduced by Nilsson, Stokes, and Thorstensson (1985). This method incorporated force transducers attached to a flexible tube. The tube deformed and produced a voltage signal upon contact with the surface. This method was favorably validated against force plate data and was used successfully in the authors' clinic for over a year. Two limitations of this procedure are the necessity of a flat surface and that the shoes worn must be modified to accomodate the tube.

Another pressure transducing device was reported by Cavanagh, Hennig, Bunch, and MacMillan (1983). This device consisted of an array of 499 piezoelectric ceramic transducers embedded in silicone rubber. Power was provided via a cable from an external source. The device was constructed to be utilized in the runner's shoe since "many foot pathologies are the result of the development of abnormal forces at locations inside the shoe" (Cavanagh et al., 1983, p. 1089). Hennig, Cavanagh, and MacMillan (1983) used the same system to measure compressive stress pulses that peaked at values as high as 1500 KPa with an accuracy of a few percent. In both studies it was found that there were large areas of stress over the first and second metatarsals, and particularly over the hallux (great toe).

In a study that was the first to use shear-sensitive, cholesteric crystals to measure pressure distribution, Scranton and McMaster (1976) demonstrated that during walking there was a smooth progression of force distribution from heel-strike through push-off. They also found that while running, the metatarsal region of the foot bore more weight with an increase in the duration of support by the toes as compared to walking. In addition, they found that the time from heel strike to metatarsal and great toe contact decreased as locomotion speed increased.

In 1982 the electrodynogram (EDG) was introduced by the Langer Biomechanics Group, Inc. This device utilized seven wafer-thin pressure transducers attached directly to the plantar surface of the foot. The transducers collected data which were stored in a self-contained microprocessor worn around the subject's waist. The data were then transferred to a computer for analysis. The EDG system does not require a large power source, unlike some of the aforementioned devices. This makes it portable and useful for collecting data in the field.

Although there is limited information published on the use of the EDG, Feehery (1986) reported that the results from his clinical use of the EDG in diagnosing running-related injuries were quite reproducible. Likewise, in a report to the Langer Biomechanics Group, Bates, McCaw, Simpson, and Dufek (unpublished, 1985) found the EDG data to compare favorably with force platform data. They did point out however, that the EDG data were more variable than the force platform data. They suggested that this variability was related to having seven separate readings for each foot rather than one composite reading as with the force platform.

Skeletal Transients and Shock Wave Attenuation

Another factor studied with regard to running-related injuries has been how the human body attenuates the shock imposed upon it. As stated by Harrison et al. (1987), "Implications are that running style can affect joint forces, and examination of these forces, how they change with footwear, speed, fatigue, and the surface run on, may be significant in understanding the etiology of sports injuries" (p. 860).

The bones and soft tissues are the major shock absorbers of the human body (Wosk & Voloshin, 1981). Wosk and Voloshin (1981) reported that repetitive loading, such as occurs during running, results in degenerative conditions in joints. Radin, Parker, Pugh, Steinberg, Paul, and Rose (1973) substantiated this finding with a study using rabbits. They found that repetitive impulsive loadings caused changes in cartilage preceeded by bony stiffening. The researchers reported that the results of the study supported the notion that joint degeneration can be caused by repetitive impulsive loadings. However, two relatively recent studies indicate that osteoarthritis appears not to be more prevalent in runners than in non-runners of the same age (Lane, Bloch, Jones, Marshall, Wood, & Fries, 1986; Panush, Schmidt, Caldwell, Edwards, Lougley, Yonker, Webster, Nauman, Stark, & Petterson, 1986).

Voloshin, Burger, Wosk, and Arcan (1985) have shown that the heel-strike spike is the major source of shock wave moving through the musculoskeletal system. Other researchers (Dickinson et al., 1985; Light et al., 1980), are in agreement.

Surfaces

Few studies have dealt with the surface a runner must encounter. Most of the studies reported in the literature have dealt with surfaces in a controlled laboratory setting rather than in the field. Furthermore, little attention has been given to the hardness characteristics of surfaces used in such studies. This is somewhat surprising when one considers that several authors have reported hard surfaces as a high risk factor in running-related injuries (Brody, 1980; Butler, 1982; James et al., 1978; McKenzie et al., 1985; McKenzie et al., 1986; Nigg, 1985; Roy & Irvin, 1983; Subotnick, 1985).

The contention that harder surfaces have a detrimental effect is substantiated by a study conducted by Radin et al. (1982) in which sheep were subjected to four hours per day of slow walking on a circular concrete floor. This group of sheep was also pastured on a hard surface. Another group of sheep was subjected to the same routine of walking but the floor was covered in wood chips. This group of sheep was allowed to pasture on grass. After nine months all of the sheep that had walked on concrete had developed a noticeable limp. After two and a half years all sheep were sacrificed and it was found that the sheep that walked on concrete had developed cortical thickening in the distal femoral subchondral bone. There was also a depletion of hexosamine in both the weight-bearing and non-weight-bearing articular cartilage which is associated with an early cartilaginous change in osteoarthrosis. It is important to note is that the only joint affected by the treatment was the knee. The sheep that walked on the more compliant surface exhibited no deleterious changes.

On a more anecdotal note, MacLellan (1984) stated, "In Britain we have problems with our cricketers who train on relatively soft grass during the English cricket season and then travel overseas to compete on hard and unyielding surfaces, with a high injury rate as a consequence." Nigg, Denoth, Kerr, Luethi, Smith, and Stacoff (1984) cited similar problems with pain in the lower back and knees among tennis players who play on hard synthetic surfaces rather than on grass or clay courts.

Three studies deal directly with surfaces and distance runners. Al-Hasso & Sawhill (1988) used 10 healthy male subjects to investigate the effects of 10 selected sport surfaces on ground reaction forces during walking and running. They found that while running on the softer surfaces, subjects exhibited longer contact times than reported in the footwear literature. The authors concluded that these surfaces "offered more mechanical safety by extending the reaction forces over longer durations" (p. 6). Unfortunately, exactly which of the selected sport surfaces were thought to be safer was not specified.

Feehery (1986) used an accelerometer and a force platform to study the influence of asphalt, concrete, and grass on ground reaction forces exhibited by runners. Feehery found that the braking phase while running on concrete was longer than that found on asphalt or grass. He proposed that "since the runner senses the concrete is the hardest surface, it appears that he is slowing down the most in an attempt to cushion landing" (p. 656). Adaptation in running kinematics on different surfaces has also been postulated by Nigg (1985). Nigg stated, "Runners seem to adapt to these changes (magnitude of the external forces) by changing the velocity of landing and/or geometry of the lower extremities during landing" (p. 377).

Feehery found that it took longer for the vertical forces measured at the foot to reach the head while the subject was running on grass rather than on concrete or asphalt. This phenomenon is thought to be responsible for the perception that running on grass lowers the force at impact, although in fact, the force on the grass is equal to or slightly greater than that found on asphalt or concrete. Feehery did point out however, that because it has been suggested that it is the transient shock wave produced at impact that may result in joint degeneration, it would be of benefit to run on a surface where the shock wave takes longer to attenuate but running speed is not adversely affected.

The third study dealing with running surface and distance runners focused on the effect of surface compliance on speed and injuries in distance runners. McMahon and Greene (1978, 1979) postulated that there is an optimal running surface compliancy that is neither too soft, nor too hard. They tested this hypothesis on an indoor track, which they called a "tuned track", at Harvard University. They described the surface as a spring and found that if the stiffness of the spring is closely tuned to the mechanical properties of the human runner, the runner's speed can be increased. Their "tuned" track has reportedly led to faster times and fewer injuries (due to foot forces being greatly attenuated). Cuin (1984) reported similar findings on a "tuned track" at Yale University that was modelled after the one at Harvard.

Summary

A review of the relevant literature on running kinematics, ground reaction forces, pressure distribution, skeletal transients and shock wave attenuation, and surfaces reveals that: (a) The majority of studies on running kinematics have dealt with optimal stride lengths, and stride rates, or with running economy, (b) vertical ground reaction forces of 1.5 to 3 times the body weight of the runner have been documented, and it has been shown that these forces increase with an increase in speed, (c) several methods of obtaining plantar pressure distribution data have been reported, (d) the sustenance of repetitive impact forces during running may or may not contribute to degenerative processes at joints, and (e) more compliant surfaces such as grass may lead to fewer running-related injuries.

CHAPTER III

METHODS

This section of the study deals with the methods for obtaining data. The methods chapter will include the following sections: (a) Apparatus, (b) Pilot Study, (c) Subjects, (d) Procedures, (e) Experimental Design, and (f) Statistical Analysis.

Apparatus

The apparatus used for the collection of pressure data was an electrodynogram (EDG) system (Appendix B). This device was introduced in 1982 by the Langer Biomechanics Group, Inc. Although there is limited information published on the use of the EDG, Feehery (1986) reported that the EDG data collected in his running clinic was "quite reproducible, as demonstrated by multiple trials, as long as the sensors are not removed" (p. 60). The EDG has also been tested for intra-and inter-day reliability by Bates, et al. (unpublished, 1985) and found to yield data comparable to those acquired with a force platform. They did point out, however, that the EDG data were more variable than the force platform data. They suggested that this variability was related to having seven separate readings for each foot rather than one composite reading as in the case of the force platform.

The EDG consists of seven wafer-thin flexible pressure transducers. These were attached to the plantar surface of each foot with an adhesive strip provided with the EDG. However, early in the study two sensors from each foot were rendered inoperable during data collection when the transducers broke away from the lead wires connected to the data collector. This made it necessary to attach the remaining five sensors over the first and fifth metatarsals, the hallux, and the medial and lateral calcaneal regions. Because the EDG apparatus for each foot was not calibrated, accurate between feet comparisons were not possible in this study. The pressure data were stored in a six ounce self-contained microprocessor and storage unit worn in a belt around the subject's waist. After each test, the waist recorder pack was plugged into the EDG computer console where the data were then transferred to an IBM PC-AT computer for data analysis, interpretation, and print-out using the software provided with the EDG system.

A Redlake LOCAM 16mm high-speed camera was used for the collection of kinematic data. Each subject was filmed at 100 fps. from the left sagittal view with black and white Tri-X reversal film. Three 1 meter sticks on stands were utilized as scale devices within the field of view.

Pilot Study

A pilot study familiarized the researcher with (a) the use of the LOCAM camera and (b) the use of the electrodynogram (EDG) system. In addition, the researcher experimented with the use of the transducers on the outside of the shoe, as well as on the inside of the shoe. This proved to be an educational venture as the transducers were found not to be durable enough to withstand the forces exerted on the outside of the shoe.

Three subjects were used in the pilot study. The following joint centers were marked with adhesive stickers partitioned into alternating black and white quadrants prior to filming: right lateral ankle, right lateral knee, right hip, right shoulder, right elbow, right wrist, left medial ankle, left medial knee, left elbow, and left wrist. The subject was then filmed at 100 fps. on three surfaces: grass, concrete, and a tartan track.

The collection of pressure data using the EDG occured on the same three surfaces. Data were collected with the transducers positioned over the first, second, third, and fifth metatarsals, the hallux, and the medial and lateral calcaneal region of the plantar surface of the foot. The

EDG data indicated a larger amount of pressure over the first and second metatarsals than at other sites for all three subjects. This finding is consistent with those of other researchers (Hennig, et al., 1983).

The kinematic parameters studied were stride length, stride rate, swing time, single leg support time, and running speed. Due to problems with the camera, kinematic data were available for only one of the three subjects. For this subject, stride rate, swing time, and single leg support time were very consistent on all three surfaces. Stride length, however, was longest on grass and shortest on concrete. In addition, it was found that 100 fps is an adequate film transport speed for evaluating kinematic changes on different surfaces. The conclusions drawn pertaining to the EDG data and the kinematic data are in general agreement with the current literature.

Subjects

The subjects for this study were 14 experienced male varsity-level collegiate distance runners (mean age: 20.57, ±2.95 years; mean height: 179.98, ±6.90 cm; mean weight: 68.36, ±6.46 kg; mean weekly mileage 68.08, ±10.54 km). Prior to data collection each of these subjects read and signed an informed consent form (See Appendix A). Each subject was minimally attired in shorts and a new pair of Nike Rio II running shoes (supplied by

Nike Inc.) The number of subjects was selected based on achieving a power level of .80 for detecting a 1 standard deviation difference among means when type I error was set at .10. However, kinematic data could be assessed for only twelve of the fourteen subjects due to problems with the camera. This resulted in a slightly lower power level for comparisons among the kinematic variables.

Procedures

For collection of the EDG data, each subject was instructed to run at a pace of six minutes/mile (4.47 m/s). To facilitate maintenance of this pace, subjects listened to a recording of the beat of a predetermined cadence through headphones attached to a portable audio tape player during the data collection. The beat recording was taken prior to the investigation from a metronome set to the stride cycle of an experienced runner on a treadmill set at 4.47 m/s. Each subject ran at this designated pace for approximately fifty to sixty meters prior to activation of the EDG microprocessor via remote control by the researcher. The EDG microprocessor then stored data over the next 4 stride cycles. Immediately following each trial, the collected data were transferred to an IBM PC-AT computer, which generated a print-out of the results. The variables quantified were steps/min., single leg support time (stance), swing time, and pressure at the five previously identified sites on the plantar surface of each foot. Pressure data were collected at a frequency of 200 Hz. This procedure was repeated for each subject on five different surfaces of varying hardness--grass, concrete, asphalt, cinders, and a tartan track--in random order. It should be pointed out that a quantification of each surface's hardness was not calculated. However, this lack of quantification is consistent with the present related literature.

Each joint center was marked appropriately with either a black felt pen or an adhesive sticker partitioned into alternating black and white quadrants prior to the collection of film data. The joints marked included the left lateral ankle, left lateral knee, left hip, right medial ankle, and right medial knee.

Each subject was then filmed from the left sagittal view while running at the same pace (6 min/mile), as set by the beat on the headphones. This process was repeated with subjects running on each of the five selected surfaces, with the surfaces ordered randomly.

The film data were digitized frame by frame over one complete stride cycle of the left leg. Variables quantified included stride length (the distance traveled between successive contact points of the same foot), stride rate (the inverse of stride time which is the time between successive contacts of opposite feet), single leg support time (the time that the foot is in contact with the ground), swing time (time between successive ground contacts of one foot), and speed (stride length multiplied by the stride rate). Stride length was quantified as the scaled digitized length between successive contacts of the left foot. Stride rate was calculated as film speed divided by the number of frames per stride. Running speed was estimated from the calculated stride length multiplied by the calculated stride rate.

Experimental Design

The design of this study entailed a single group with repeated measures taken to ascertain the effect of the five surfaces on five pressure recordings (i.e. hallux, first metatarsal, fifth metatarsal, medial calcaneal region, and lateral calcaneal region) and on five running kinematic variables (stride length, stride rate, single leg support time, swing time, and running speed). The major variables controlled were the sample, the surfaces, the pace, and the shoes. All subjects wore the same style of running shoe and ran at the same pace, since both of these variables can affect both plantar pressure distribution and running kinematics.

Statistical Analysis

Three statistical analyses were conducted to explore the statistical hypotheses outlined in Chapter I. A one-way repeated measures ANOVA was utilized to compare the pressure data across surfaces for each EDG sensor site separately. A two-way (surface x site) repeated measures ANOVA was used to analyze the interaction of sensor site and surface. EDG data for left and right feet were analyzed separately because the EDG pressure sensors for each foot were not calibrated prior to data collection. Separate one-way repeated measure ANOVAs were also run for each kinematic variable quantified (i.e., stride length, stride rate, single leg support time, swing time, and running speed) across running surfaces. Running speed was of interest only because of its potential effects on the other kinematic variables. The quantification of running speed and the calculation of ANOVA for speed was therefore to show that there were, in fact, no differences in running speed. The statistical software utilized was BMDP2V (1985). The alpha level selected for use in this study was 0.10 because of the expected subtlety of the changes in the kinematic and pressure distribution parameters.

CHAPTER IV

Results and Discussion

The results and discussion chapter includes separate sections on left and right foot EDG data, followed by discussion of the variability of the EDG data. A section on running kinematics is then presented, followed by a chapter summary.

Left Foot Pressure Recordings

The results of the analysis of variance for each pressure transducer site separately are presented in Tables D1-D5 in Appendix D. Table D6 displays the two-way ANOVA table for the left EDG data. Also in Appendix D are tables (D7-D20) of EDG data for each of the 14 subjects, as well as composite tables (D21-D25) for all fourteen subjects on each of the five surfaces. All Appendix D tables include the means and standard deviations for each sensor across all five surfaces.

The analyses of variance for pressure revealed that at only one sensor site, the fifth metatarsal, was there a statistically significant ($p < 0.10$) difference in pressure across surfaces. A Dunn-Bonferroni post hoc pairwise comparison presented in Table 1 reveals that the comparisons between grass and asphalt, grass and tartan, grass and concrete, cinders and tartan, and finally cinders and concrete were significantly different. This is graphically depicted in Figure 1 where it can be seen that there is a higher degree of variability at this sensor site. Table 2 exhibits the means and standard deviations for pressure data of each of the sensor sites on each of the five surfaces.

The Dunn-Bonferroni pairwise comparisons for the fifth metatarsal show that the harder surfaces--asphalt, concrete, and tartan--produced higher pressures than did the softer surfaces--grass and cinders. Although this result makes sense intuitively, other research has indicated that the impact forces on softer surfaces (such as grass) may be as much or more than those found on harder surfaces, such as concrete (Feehery, 1986). This may account for the lack of significant differences at the other four sites.

Also of interest is the expected variability among sensor sites. As can be seen graphically in both Figure 1 and Table 2, the mean pressure values for the first metatarsal far exceed those found at the other pressure transducer sites. The areas of next highest pressures were the fifth metatarsal and the hallux. The lowest pressure sites were the medial and lateral calcaneal regions. These findings are consistent with those reported by others (Cavanagh & LaFortune, 1980; Hennig et al., 1983) as well as with the pilot study data for the present investigation.

The two-way ANOVA (i.e., surface x site) was statistically non-significant. Although speculative, this finding may corroborate Nigg (1985) and Feehery's (1986) postulation that the runner senses the difference in the surface hardness and consequently makes kinematic adaptations in an effort to better absorb the force at impact.

Table 1
DUNN-BONFERRONI

Left EDG Data - Fifth Metatarsal

	Y4	Y2	Y5	Y1	Y3
Y4 = 1.320	--	.073	.126*	.171*	.200*
Y2 = 1.393	--	--	.053	.098*	.127*
Y5 = 1.446	--	--	--	.045	.074
Y1 = 1.491	--	--	--	--	.029
Y3 = 1.520	--	--	--	--	--

Y4 = Grass

Y2 = Cinders

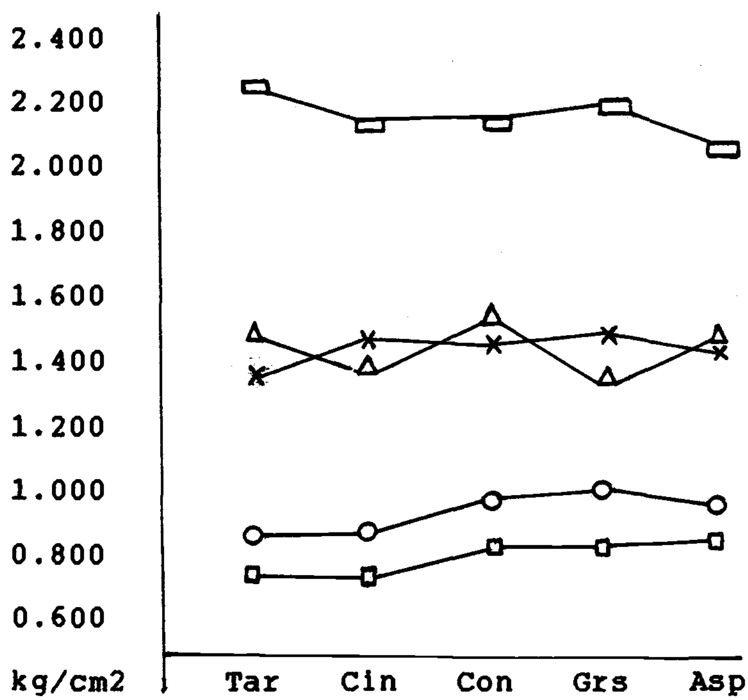
Y5 = Asphalt

Y1 = Tartan

Y3 = Concrete

*exceeded critical difference:
t(52,.10,10) = .0906

Figure IV.1
Left EDG



Sensor Sites:

○ = Lateral Calcaneal Region

□ = Medial Calcaneal Region

Δ = Fifth Metatarsal

X = First Metatarsal

▭ = Hallux

Surfaces:

Tar: Tartan

Cin: Cinders

Con: Concrete

Grs: Grass

Asp: Asphalt

Table 2
Left EDG Data

Means and Standard Deviations

	S1	S2	S3	S4	S5
L	0.890a (0.358)b	0.933 (0.460)	1.006 (0.382)	1.087 (0.340)	1.014 (0.415)
M	0.761 (0.303)	0.757 (0.268)	0.804 (0.332)	0.801 (0.188)	0.819 (0.321)
5	1.491 (0.318)	1.393 (0.314)	1.520 (0.298)	1.320 (0.340)	1.446 (0.310)
1	2.226 (0.801)	2.146 (0.667)	2.153 (0.869)	2.190 (0.887)	2.070 (0.696)
H	1.377 (0.310)	1.459 (0.246)	1.449 (0.333)	1.449 (0.309)	1.426 (0.282)

Sensor:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux

Surface:

S1: Tartan
S2: Cinders
S3: Concrete
S4: Grass
S5: Asphalt

Units: kg/cm2

a: Mean
b: Standard Deviation

Right Foot Pressure Recordings

The results of the ANOVA's for right foot EDG data for each site separately are presented in Tables E1-E5 in Appendix E. Table E6 gives the 2 x 2 ANOVA table for analyzing the surface x site interaction for right foot data. Also in Appendix E are tables (E7-E20) of right foot EDG data for each subject, as well as composite tables for all fourteen subjects on each of the five surfaces (Tables E21-E25). Included in each of these tables are the means and standard deviations for each pressure transducer site across all five surfaces.

Among the analyses of variance for separate pressure transducer sites, only the one for the medial calcaneal region yielded a statistically significant ($p < 0.10$) F value. The Dunn-Bonferroni post hoc pairwise comparison for the medial calcaneal region is presented in Table 3. This analysis revealed that the comparisons between cinders and concrete, cinders and asphalt, cinders and grass, tartan and concrete, tartan and asphalt, tartan and grass, and concrete and grass were significantly different. The highest area of pressure was exhibited while running on grass with concrete and asphalt following in descending order. This is graphically illustrated in Figure 2.

Feehery (1986) also found that the heel strike vertical spike as measured by a force platform was higher on grass than on concrete. The highest pressures were once again exhibited by the fifth and first metatarsals, and the hallux, respectively, as may be observed in both Figure 2 and Table 4.

A significant ($p < 0.10$) F value was also calculated for the surface x site interaction from the right foot data. Dunn-Bonferroni post hoc contrasts revealed that differences between the first and fifth metatarsal means on concrete were greater than those found at the same two transducer sites on grass. The higher pressures present on the medial calcaneal region on grass may account for the attenuation of pressure exhibited by the metatarsals on the same surface. Likewise, the higher amounts of pressure exhibited on concrete by the metatarsals may be related to the lower amounts of pressure shown at the calcaneal region on concrete.

Table 3
DUNN-BONFERRONI

Right EDG Data - Medial Calcaneal Region

	Y2	Y1	Y3	Y5	Y4
Y2 = 0.959	--	.017	.147*	.170*	.284*
Y1 = 0.976	--	--	.130*	.153*	.267*
Y3 = 1.106	--	--	--	.023	.137*
Y5 = 1.129	--	--	--	--	.114
Y4 = 1.243	--	--	--	--	--

Y2 = Cinders

Y1 = Tartan

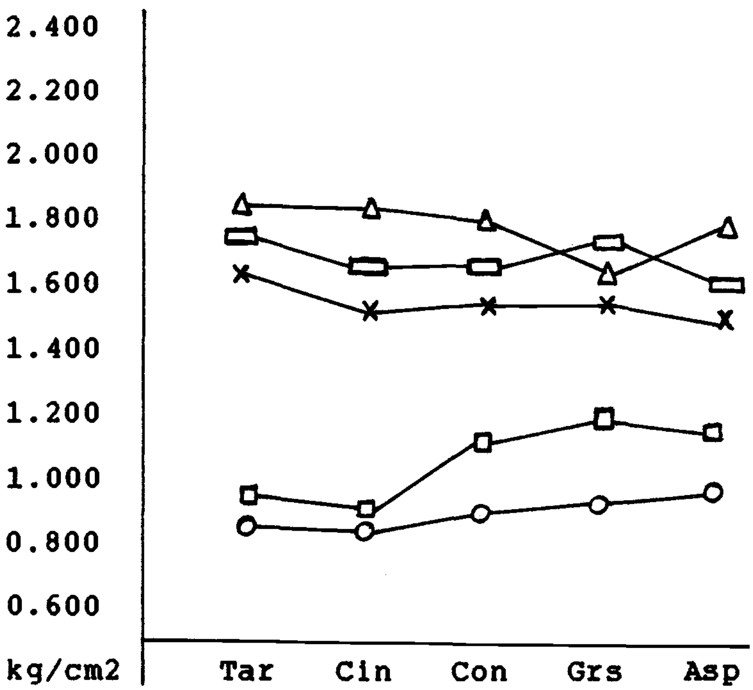
Y3 = Concrete

Y5 = Asphalt

Y4 = Grass

*exceeded critical difference:
t(52,.10,10) = 0.1164

Figure IV.2
Right EDG



Sensor Sites:

○ = Lateral Calcaneal Region

□ = Medial Calcaneal Region

Δ = Fifth Metatarsal

X = First Metatarsal

▭ = Hallux

Surfaces:

Tar: Tartan

Cin: Cinders

Con: Concrete

Grs: Grass

Asp: Asphalt

Table 4
Right EDG Data

Means and Standard Deviations

	S1	S2	S3	S4	S5
L	0.873a (0.364)b	0.867 (0.402)	0.911 (0.338)	0.986 (0.312)	0.994 (0.403)
M	0.976 (0.439)	0.959 (0.473)	1.106 (0.484)	1.243 (0.352)	1.129 (0.472)
5	1.856 (0.653)	1.846 (0.570)	1.827 (0.517)	1.686 (0.411)	1.824 (0.551)
1	1.751 (0.525)	1.679 (0.524)	1.689 (0.436)	1.737 (0.599)	1.649 (0.468)
H	1.619 (0.468)	1.530 (0.392)	1.546 (0.422)	1.546 (0.376)	1.530 (0.407)

Sensor:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux

Surface:

S1: Tartan
S2: Cinders
S3: Concrete
S4: Grass
S5: Asphalt

Units: kg/cm2

a: Mean
b: Standard Deviation

Variability of the EDG Data

The EDG data displayed marked variability at each sensor site, on each surface, by each of the 14 subjects, and between left and right feet. Because the differences between the left and right feet may be attributable to a lack of calibration in the EDG apparatus or to intrasubject variability, between feet comparisons must be viewed with caution. For example, subject 11 produced the highest recorded pressure with 4.000 kg/cm2 on the left first metatarsal while running on grass. The lowest reading (0.100 kg/cm2) was exhibited by subject 3 over the left medial calcaneal region on the asphalt surface. Several other subjects also exhibited the lowest pressure readings at the calcaneal regions and the highest at the metatarsal region of the foot. However, it was expected that a higher degree of variability would be exhibited from one surface to another than was in fact documented. The relative consistency of pressure recordings across surfaces supports the postulation of Feehery (1986) and Nigg (1985) that the runner senses that the surface is harder and adjusts accordingly.

Perhaps of more practical significance were the marked differences in pressure recordings among the sensor sites. Although this was an expected outcome, the magnitude of the differences exhibited was surprising. As described in the preceeding paragraph, the present investigation shows profoundly larger areas of pressure in the metatarsal region as opposed to the calcaneal region of the plantar surface of the foot. These findings are consistent with those of Cavanagh & LaFortune (1980), Hennig et al. (1983), and Scranton & McMaster (1976). This may suggest that the metatarsal region merits more attention by the shoe manufacturers than presently appears to be the case.

Running Kinematics

The kinematic variables of interest were stride length, stride rate, single leg support time, swing time, and running speed. The results of the ANOVA's for each of these variables are presented in Tables F1-F5 in Appendix F. Also in Appendix F are tables for the kinematic data of individual subjects (Tables F6-F11), as well as composite tables (Tables F12-F16) for twelve subjects on each of the five surfaces. Included in these tables are the means and standard deviations for each variable across all five surfaces.

The F value for only one variable, stride rate, was shown to be statistically significant ($p < 0.10$). The Dunn-Bonferroni post hoc pairwise comparison for stride rate is presented in Table 5. The comparisons between concrete and all of the other surfaces--asphalt, cinders, grass, and tartan--and the differences between asphalt and tartan, and asphalt and cinders were statistically significant. Of interest is that both of these surfaces--concrete and asphalt--are considered to be the hardest of the five surfaces studied. It should be noted however, that the differences are extremely small; 1.41 strides/sec. (slowest stride rate) on concrete as opposed to 1.45 strides/sec. (fastest stride rate) on both tartan and cinders. This is graphically illustrated in Figure 3. In Table 6 the means and standard deviations are given for all variables on all surfaces. The slower stride rates on these two surfaces may reflect an attempt by the subjects to attenuate the force of the impact with the surface. This contention is substantiated by Feehery (1986) and Nigg (1985). To further corroborate this contention, the speed exhibited by the subjects while running on concrete is also the slowest among those for the five surfaces tested. However, the speed subjects exhibited while running on asphalt is the second fastest of the five surfaces tested. This was due though, to a longer stride length and a faster stride rate than were exhibited while running on concrete.

Although the target running speed in the present investigation was 4.47 m/s, the mean running speed calculated for every surface was somewhat faster. This appears to be due to the slightly longer stride lengths exhibited by the subjects than have been reported in other investigations where subects ran at a similar speed (Elliot & Ackland, 1981; Elliott & Blanksby, 1979).

Surprisingly small differences were recorded across surfaces for single leg support time and swing time. This is interesting when one considers that the role of the single leg support phase is to cushion the body from shock and to support the body as it moves forward (Slocum & James, 1968). The present data indicate that the longest periods spent in single leg support were found on the softest surfaces--grass and cinders. Although these were small differences, however, that were not statistically significant, the increase in ground contact time may have had a concomitant increase on the mechanical safety for the runner. This contention is substantiated by the research of Al-Hasso & Sawhill (1988).

Another kinematic variable that was evaluated qualitatively from the film was running style. The heel-toe running style was the predominant style used on all surfaces. The midfoot style was the next preferred style with three subjects using this style on tartan, one on asphalt and concrete, and two on grass and cinders. Running style may have affected the EDG readings, particularly in the metatarsal region of the foot.

Table 5
DUNN-BONFERRONI

Kinematic Data - Stride Rate

	Y3	Y5	Y4	Y1	Y2
Y3 = 1.41	--	.02*	.03*	.04*	.04*
Y5 = 1.43	--	--	.01	.02*	.02*
Y4 = 1.44	--	--	--	.01	.01
Y1 = 1.45	--	--	--	--	.00
Y2 = 1.45	--	--	--	--	--

Y3 = Concrete

Y5 = Asphalt

Y4 = Grass

Y1 = Tartan

Y2 = Cinders

*exceeded critical difference:
t(44,.10,10) = .0184

Table 6
Kinematic Data

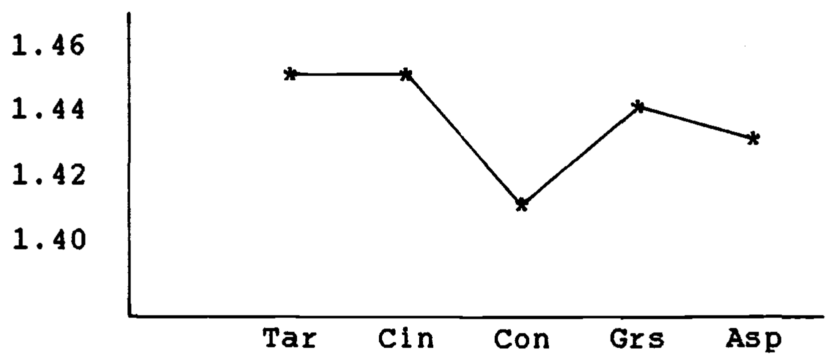
Means and Standard Deviations

	S1	S2	S3	S4	S5
SL	3.63a (0.586)b	3.47 (0.321)	3.48 (0.443)	3.54 (0.348)	3.57 (0.485)
SR	1.45 (0.054)	1.45 (0.069)	1.41 (0.062)	1.44 (0.456)	1.43 (0.076)
SLS	28.40 (3.029)	29.32 (1.688)	28.69 (2.833)	29.40 (2.799)	28.58 (2.756)
SW	71.60 (3.029)	70.68 (1.688)	71.31 (2.833)	70.60 (2.799)	71.42 (2.756)
SP	5.27 (0.798)	5.03 (0.425)	4.91 (0.623)	5.09 (0.521)	5.12 (0.737)

Kinematics:	Units:	Surface:
SL: Stride Length	meters	S1: Tartan
SR: Stride Rate	#strides/sec.	S2: Cinders
SLS: Single Leg Support	%gait cycle	S3: Concrete
SW: Swing Time	%gait cycle	S4: Grass
SP: Speed	meters/sec.	S5: Asphalt

a: Mean
b: Standard Deviation

Figure IV.3
Running Kinematic Data
Stride Rate



Unit: * = number of strides/second

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Summary

In summary, only one left foot sensor site, the fifth metatarsal, showed significant differences across surfaces. It was found that the pressure recordings for this site were higher on the harder surfaces. This was also the case in the right foot 2 x 2 ANOVA. Larger areas of pressure were exhibited for the first and fifth metarsals while running on concrete. The other site exhibiting significant differences was the right medial calcaneal region. This sensor recorded larger pressure readings while running on the softest surface. A phenomenon that is consistent with other research (Feehery, 1986). It can be generally stated then, that based on the sites that were statistically significant, the metatarsal region of both feet were subjected to larger amounts of pressure while running on harder surfaces. This finding may suggest that adequate shock absorption occurs in the calcaneal region of the shoe used in this study, and/or the metatarsal region of the foot-shoe interface may merit more attention than is commonly thought. This contention is substantiated by the research of Cavanagh & LaFortune (1980).

Only one kinematic variable, stride rate, showed significant differences across surfaces. The differences observed may be representative of a tendency of runners to slow down on concrete and therefore attenuate as much force as possible. Small non-significant differences were found in the other variables across each of the surfaces. These findings may indicate that the commonly studied kinematic variables (i.e., stride length, stride rate, single leg support time, and swing time) may be too subtle or may not be the real kinematic variables of interest. An investigation of how joint angles are affected may further elucidate this study. Running style may have affected the EDG readings, particularly in the metatarsal region of the foot.

CHAPTER V

Conclusions and Recommendations

This chapter presents conclusions pertaining to the EDG based findings and the results of the analysis of running kinematics. Recommendations for further research are also given.

Conclusions

In general, slight differences between the means of each individual EDG sensor site across all five surfaces were exhibited. This finding is thought to support the postulation that the runner senses that a surface is harder and adjusts accordingly. The same postulation is supported by the fact that small differences were also observed in three of the kinematic variables (i.e. stride length, single leg support time, and swing time). However, single leg support time was longer on the softer surfaces (i.e. grass and cinders). It is thought that this increase in contact time may increase the mechanical safety for the runner (Al-Hasso & Sawhill, 1988).

Within the limitations of the data collection procedures the following specific conclusions are warranted:

1. Higher pressures appear to be produced under the left fifth metatarsal for individuals running on harder

surfaces than on softer surfaces.

2. Higher pressures are present in the metatarsal region than in the calcaneal region of the plantar surface of the foot for individuals running in the shoes selected for this study (especially while running on harder surfaces).

3. Stride rate appears to be slightly reduced on harder surfaces such as concrete and asphalt as compared to softer surfaces such as tartan, cinders, and grass.

Until further evidence is forthcoming, physical educators and coaches should encourage their students and athletes to do some of their running on softer surfaces.

Recommendations

The following methodological and descriptive considerations are recommended for future research:

1. A pressure sensing apparatus should be utilized that is specifically designed to collect running data in the field. This apparatus should be durable, easily calibrated, valid and reliable, and able to interface with kinematic data collection instruments.

2. Quantification of hardness characteristics of surfaces is warranted.

3. The use of an accelerometer, electromyography,

and/or any other suitable piece of equipment may provide insight as to how quickly the force travels through the human body and which muscles are most active across different surfaces.

4. A comparison study of barefoot, in-shoe, and plantar surface of the shoe should prove useful. This information may reveal important information pertaining to exactly how much force a shoe really attenuates.

5. A study of the interaction of varying surfaces, speed, distance, fatigue, population, and incline/decline of surface should be investigated.

6. The kinematics should be expanded to investigate joint angles, acceleration, velocity, etc.

7. An investigation into the runner's perception of surface hardness could add another dimension to the study of this complex problem.

It is apparent from the results of the present investigation as well as the related studies, that the effects of running on different surfaces involve complex issues. This problem merits further investigation to improve our understanding of how various surfaces affect the human body during running. Further investigation in this area should also serve to further expand our understanding of running-related injuries and shoe and surface design.

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APPENDICES

APPENDIX A

SUBJECT CONSENT DOCUMENT

OREGON STATE UNIVERSITY

Subject's Name:
Current Address:
Phone Number:

Project Title: The Effect of Surface Type on Plantar Pressure Distribution and Running Kinematics.

The purpose of this study is to quantify pressure distribution and indicators of running form for subjects running on five different surfaces. Pressure data will be collected using small, thin transducers that will be attached to the plantar surface of each subject's foot with an adhesive strip. This should cause very little, if any, discomfort. A short film clip will also be taken of each subject to serve as a record of running form. Prior to the data collection each subject's joints will be marked with a felt tip pen or adhesive sticker. Once again, this should cause little, if any, discomfort. You will be asked to run at a pace of six minutes/mile on the five different surfaces--grass, concrete, asphalt, cinders, and a tartan track. Data collection should take approximately one to two hours. All data collected, especially film data, will remain confidential.

It is the hope that this investigation will further the knowledge and understanding of the etiology of running-related injuries and substantiate the advice to run on softer surfaces.

Certification

I fully understand the activity in which I am participating and the procedures which will be performed. I have had an opportunity to ask questions and understand that I may ask questions as the study progresses. I understand that I am participating in this study of my own free will and I am free to withdraw my consent and discontinue my participation at any time without any penalty.

Date: Signature of Subject:

APPENDIX B

Electrodynogram (EDG) Illustration

Fig.1: Six ounce waist recorder (microprocessor) with lead wires

Fig.2 Plantar surface pressure transducers (7)

H = Hallux
1 = First Metatarsal
2 = Second Metatarsal
5 = Fifth Metatarsal
L = Lateral Calcaneal
M = Medial Calcaneal
X = Floating Sensor

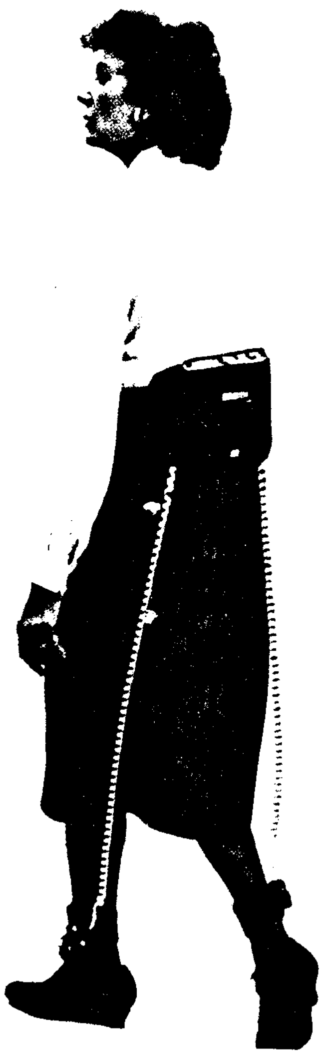

Fig.1

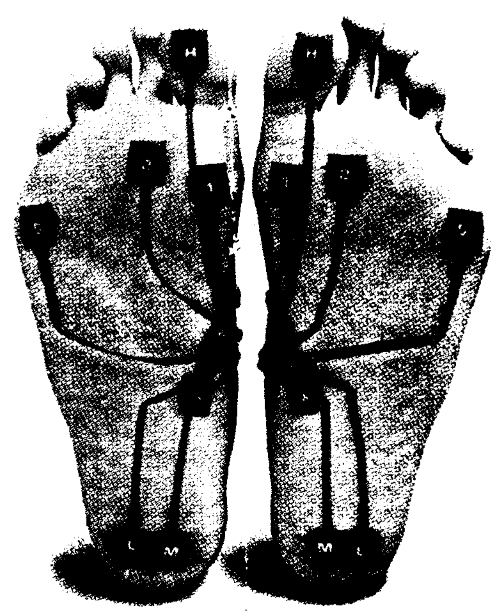

Fig.2

Langer Biomechanics, Inc., 1985

APPENDIX C
Subject Profile

Name:____

Gender:______ Age:______ Height:________ Weight:__________

Running Shoe: Brand:________ Model:_________ Size:_______
Number of miles run in this pair of shoes:________________

Weekly Mileage:____

Injury History:____
____
____
____
____
(Please be as complete as possible).

Number of years of competitive running:______ Awards:_____
____
____

____
(Please do not write below this line).

Temperature:____

Surface:____

Surface Condition:_______________________________________

Weather:____

Notes:____
____
____
____
____

APPENDIX D
TABLE D1
ANOVA TABLE

Left EDG Data - Lateral Calcaneal Region

Source	SS	df	MS	p
Surface	.328	4	.0821	.14
Error	2.349	52	.0452	
Total	2.677	56	--	

TABLE D2
ANOVA TABLE

Left EDG Data - Medial Calcaneal Region

Source	SS	df	MS	p
Surface	.043	4	.0106	.84
Error	1.583	52	.0304	
Total	1.626	56	--	

TABLE D3
ANOVA TABLE

Left EDG Data - First Metatarsal

Source	SS	df	MS	p
Surface	.189	4	.0473	.68*
Error	6.460	52	.1242	
Total	6.649	56	--	

*Huynh-Feldt Probability

TABLE D4
ANOVA TABLE

Left EDG Data - Fifth Metatarsal

Source	SS	df	MS	p
Surface	.3570	4	.0832	.08a
Error	2.0890	52	.0402	
Total	2.4460	56	--	

a: $p \leq .10$

TABLE D5
ANOVA TABLE

Left EDG Data - Hallux

Source	SS	df	MS	p
Surface	.0603	4	.0151	.43
Error	.8041	52	.0155	
Total	.8644	56	--	

TABLE D6
2X2 ANOVA TABLE

Left EDG Data

Source	SS	df	MS	p
Surface	.10024	4	.0251	.81*
Error	4.81016	52	.0930	
Sensor	77.84037	4	19.4601	.00a*
Error	40.11979	52	.7751	
Surface X Sensor	.87757	16	.0549	.25*
Error	8.47491	208	.0407	
Total	132.22300	336	--	

a: $p \leq .10$
*Huynh-Feldt Probability

APPENDIX D

TABLE D7

Left EDG Subject:1

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	FF	FF	FF	FF	FF		
Stance	41	40	40	47	42	42.0	2.608
Swing	59	60	60	53	58	58.0	2.608
L	1.600	1.660	1.660	1.660	1.740	1.664	0.045
M	1.160	0.960	1.080	1.100	1.340	1.128	0.124
5	1.680	1.640	1.740	1.480	1.680	1.644	0.088
1	1.920	1.740	1.740	1.880	1.700	1.796	0.087
H	0.700	1.100	0.820	0.920	0.820	0.872	0.134
$\bar{X}$	1.412	1.420	1.408	1.408	1.456	1.421	0.018
SD	0.433	0.323	0.384	0.353	0.349	0.368	0.038

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE D8
Left EDG   Subject:2

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	MF	FF	FF	MF	FF		
Stance	28	28	27	29	26	27.6	1.020
Swing	72	72	73	71	74	72.4	1.020
L	0.760	0.420	0.520	0.880	0.280	0.572	0.220
M	0.420	0.340	0.380	0.600	0.100	0.368	0.161
5	1.660	1.040	1.500	1.100	1.740	1.408	0.287
1	3.400	3.020	3.300	3.500	3.020	3.248	0.197
H	1.680	1.660	1.540	1.480	1.740	1.620	0.096
$\bar{X}$	1.584	1.296	1.448	1.512	1.376	1.443	0.101
SD	1.034	0.985	1.043	1.035	1.077	1.035	0.029

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE D9
Left EDG Subject:3

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	FF	FF	FF	FF	FF		
Stance	39	44	35	26	40	36.8	6.112
Swing	61	56	65	74	60	63.2	6.112
L	0.880	0.300	0.460	0.580	0.660	0.576	0.194
M	1.080	0.480	0.580	0.620	0.680	0.688	0.207
5	1.500	1.220	1.100	0.820	1.220	1.172	0.220
1	3.500	3.160	3.160	2.820	3.020	3.132	0.222
H	1.800	1.940	1.920	1.880	1.680	1.844	0.095
$\bar{X}$	1.762	1.420	1.448	1.344	1.452	1.490	0.144
SD	0.950	1.047	1.043	0.877	0.870	0.960	0.077

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE D10
Left EDG Subject:4

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	MF	MF	FF	FF	MF		
Stance	26	25	26	32	26	27	2.530
Swing	74	75	74	68	74	73	2.530
L	0.860	0.760	1.060	0.960	0.920	0.912	0.101
M	0.760	0.780	0.700	0.760	0.660	0.732	0.045
5	1.080	0.960	1.160	1.340	1.080	1.124	0.125
1	1.740	1.740	1.660	1.800	1.660	1.720	0.054
H	1.420	1.280	1.280	1.500	1.220	1.340	0.104
$\bar{X}$	1.172	1.104	1.172	1.272	1.108	1.166	0.061
SD	0.363	0.369	0.312	0.373	0.333	0.350	0.024

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE D11
Left EDG Subject:5

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	FF	MF	FF	MF	FF		
Stance	38	33	38	34	36	35.8	2.040
Swing	62	67	62	66	64	64.2	2.040
L	1.420	1.540	1.280	1.660	1.660	1.512	0.146
M	1.060	1.060	0.760	0.960	1.220	1.012	0.151
5	1.480	1.600	1.680	1.680	1.640	1.616	0.074
1	2.040	2.020	3.160	3.020	2.140	2.676	0.530
H	1.480	1.740	1.940	2.020	1.800	1.796	0.187
$\bar{X}$	1.496	1.592	1.764	1.868	1.692	1.682	0.130
SD	0.314	0.313	0.804	0.671	0.296	0.480	0.215

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE D12
Left EDG Subject:6

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	FF	MF	HT	HT	MF		
Stance	29	28	30	32	30	29.8	1.327
Swing	71	72	70	68	70	70.2	1.327
L	0.480	0.440	0.760	0.820	0.600	0.620	0.150
M	0.300	0.400	0.580	0.520	0.500	0.460	0.099
5	1.920	1.080	1.340	1.080	1.080	1.300	0.326
1	2.600	1.680	1.600	1.600	1.680	1.832	0.386
H	1.280	1.340	1.160	1.080	1.220	1.216	0.091
$\bar{X}$	1.316	0.988	1.088	1.020	1.016	1.046	0.352
SD	0.866	0.502	0.373	0.356	0.430	0.505	0.187

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE D13
Left EDG Subject:7

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	FF	FF	FF	MF	MF		
Stance	43	38	26	23	28	31.6	7.605
Swing	57	62	74	77	72	68.4	7.605
L	0.580	1.600	0.760	0.960	1.540	1.088	0.412
M	0.480	0.960	0.400	0.660	0.820	0.664	0.208
5	1.960	1.660	1.960	1.920	1.680	1.836	0.137
1	2.260	2.260	0.460	0.760	1.480	1.444	0.744
H	1.680	1.500	1.480	1.340	1.540	1.508	0.109
$\bar{X}$	1.392	1.596	1.012	1.128	1.412	1.308	0.210
SD	0.728	0.414	0.610	0.459	0.303	0.503	0.150

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE D14
Left EDG Subject:8

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	FF	FF	FF	FF	FF		
Stance	37	35	31	32	32	33.4	2.245
Swing	63	65	69	68	68	66.6	2.245
L	0.460	0.480	0.820	1.040	0.500	0.660	0.232
M	0.600	0.660	0.780	0.820	0.500	0.672	0.117
5	1.440	1.920	1.800	1.540	1.600	1.660	0.175
1	2.440	2.440	2.680	2.820	2.820	2.640	0.171
H	1.660	1.640	1.800	1.740	1.740	1.716	0.059
$\bar{X}$	1.320	1.428	1.576	1.592	1.432	1.470	0.102
SD	0.727	0.748	0.711	0.698	0.870	0.751	0.062

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE D15
Left EDG Subject:9

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	HT	FF	FF	FF	FF		
Stance	32	43	40	51	44	42.0	6.164
Swing	68	57	60	49	56	58.0	6.164
L	1.160	1.080	1.100	1.080	1.080	1.100	0.031
M	0.880	1.040	1.060	0.780	1.080	0.968	0.118
5	1.600	1.600	1.660	1.440	1.540	1.568	0.074
1	1.640	1.880	1.880	1.700	1.920	1.804	0.112
H	1.420	1.500	1.600	1.440	1.600	1.512	0.077
$\bar{X}$	1.340	1.420	1.460	1.288	1.444	1.390	0.066
SD	0.286	0.319	0.324	0.322	0.324	0.315	0.015

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE D16
Left EDG Subject:10

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	MF	MF	HT	MF	HT		
Stance	30	31	33	37	28	31.8	3.059
Swing	70	69	67	63	72	68.2	3.059
L	0.860	0.860	1.060	0.820	1.100	0.940	0.116
M	1.080	0.700	1.060	0.780	0.960	0.916	0.152
5	1.540	1.080	1.660	1.100	1.420	1.360	0.233
1	1.940	1.540	1.740	1.660	1.500	1.676	0.157
H	1.220	1.160	1.080	1.280	1.280	1.204	0.076
$\bar{X}$	1.328	1.068	1.320	1.128	1.252	1.219	0.104
SD	0.377	0.296	0.311	0.323	0.199	0.299	0.068

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE D17
Left EDG Subject:11

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	FF	FF	FF	FF	FF		
Stance	28	37	39	34	40	35.6	4.317
Swing	72	63	61	66	60	64.4	4.317
L	0.860	1.060	1.100	1.080	1.060	1.032	0.087
M	0.820	1.060	1.500	0.960	1.060	1.080	0.228
5	1.880	1.740	1.960	1.920	1.960	1.892	0.082
1	3.700	3.600	3.600	4.000	3.300	3.640	0.225
H	1.420	1.640	1.600	1.640	1.340	1.528	0.124
$\bar{X}$	1.736	1.820	1.952	1.920	1.744	1.834	0.089
SD	1.057	0.934	0.868	1.098	0.845	0.960	0.101

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE D18
Left EDG Subject:12

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	MF	HT	MF	MF	MF		
Stance	28	28	30	30	30	29.2	0.980
Swing	72	72	70	70	70	70.8	0.980
L	0.760	1.080	1.500	1.660	1.080	1.216	0.323
M	0.480	0.680	0.920	1.060	0.760	0.780	0.199
5	0.960	1.660	1.480	1.080	1.640	1.364	0.290
1	1.060	1.920	1.980	2.020	1.940	1.784	0.364
H	1.080	1.440	1.600	1.500	1.340	1.392	0.177
$\bar{X}$	0.868	1.356	1.496	1.464	1.352	1.307	0.227
SD	0.225	0.436	0.340	0.363	0.413	0.355	0.074

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE D19
Left EDG Subject:13

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	FF	FF	FF	FF	HT		
Stance	28	29	36	36	40	33.8	4.578
Swing	72	71	64	64	60	66.2	4.578
L	1.360	1.340	1.540	1.280	1.160	1.336	0.124
M	1.160	1.100	1.160	1.040	1.100	1.112	0.045
5	1.020	1.020	1.160	1.020	1.080	1.060	0.055
1	1.840	1.960	2.020	2.040	2.040	1.980	0.076
H	1.580	1.420	1.500	1.500	1.600	1.520	0.065
$\bar{X}$	1.392	1.368	1.476	1.376	1.396	1.402	0.039
SD	0.293	0.331	0.316	0.375	0.374	0.338	0.032

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE D20
Left EDG Subject:14

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	FF	FF	FF	FF	FF		
Stance	37	37	38	38	40	38.0	1.100
Swing	63	63	62	62	60	62.0	1.100
L	0.420	0.440	0.460	0.740	0.820	0.576	0.169
M	0.380	0.380	0.380	0.560	0.680	0.460	0.139
5	1.160	1.280	1.080	0.960	0.880	1.072	0.142
1	1.080	1.080	1.160	1.040	0.760	1.024	0.138
H	0.860	1.060	0.960	0.960	1.040	0.976	0.071
$\bar{X}$	0.780	0.848	0.792	0.852	0.836	0.822	0.030
SD	0.326	0.366	0.346	0.177	0.122	0.267	0.099

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE D21

Left EDG Surface: Tartan

Sub	RS	St	Sw	L	M	5	1	H	$\bar{X}$	SD
1	FF	41	59	1.600	1.160	1.680	1.920	0.700	1.412	0.433
2	FF	39	61	0.880	1.080	1.500	3.500	1.800	1.762	0.950
3	MF	28	72	0.760	0.420	1.660	3.400	1.680	1.584	1.034
4	MF	26	74	0.860	0.760	1.080	1.740	1.420	1.172	0.363
5	FF	38	62	1.420	1.060	1.480	2.040	1.480	1.496	0.314
6	FF	29	71	0.480	0.300	1.920	2.600	1.280	1.316	0.866
7	FF	43	57	0.580	0.480	1.960	2.260	1.680	1.392	0.728
8	FF	37	63	0.460	0.600	1.440	2.440	1.660	1.320	0.727
9	HT	32	68	1.160	0.880	1.600	1.640	1.420	1.340	0.286
10	MF	30	70	0.860	1.080	1.540	1.940	1.220	1.328	0.377
11	FF	28	72	0.860	0.820	1.880	3.700	1.420	1.736	1.057
12	MF	28	72	0.760	0.480	0.960	1.060	1.080	0.868	0.225
13	FF	28	72	1.360	1.160	1.020	1.840	1.580	1.392	0.293
14	FF	37	63	0.420	0.380	1.160	1.080	0.860	0.780	0.326
$\bar{X}$	--	33	67	0.890	0.761	1.491	2.226	1.377	1.350	0.266
SD	--	5.6	5.6	0.357	0.303	0.318	0.801	0.310	0.570	0.297

Sub: Subject

RS: Running Style; FF: Forefoot; MF: Midfoot; HT: Heel-Toe

ST: Stance (percentage of gait cycle)
SW: Swing (percentage of gait cycle)

Sensor Sites: Units: kg/cm2

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE D22

Left EDG   Surface: Cinders

Sub	RS	St	Sw	L	M	5	1	H	$\bar{X}$	SD
1	FF	40	60	1.660	0.960	1.640	1.740	1.100	1.420	0.323
2	FF	44	56	0.300	0.480	1.220	3.160	1.940	1.420	1.047
3	FF	28	72	0.420	0.340	1.040	3.020	1.660	1.296	0.985
4	MF	25	75	0.760	0.780	0.960	1.740	1.280	1.104	0.369
5	MF	33	67	1.540	1.060	1.600	2.020	1.740	1.592	0.313
6	MF	28	72	0.440	0.400	1.080	1.680	1.340	0.988	0.502
7	FF	38	62	1.600	0.960	1.660	2.260	1.500	1.596	0.414
8	FF	35	65	0.480	0.660	1.920	2.440	1.640	1.428	0.748
9	FF	43	57	1.080	1.040	1.600	1.880	1.500	1.420	0.319
10	MF	31	69	0.860	0.700	1.080	1.540	1.160	1.068	0.286
11	FF	37	63	1.060	1.060	1.740	3.600	1.640	1.820	0.934
12	HT	28	72	1.080	0.680	1.660	1.920	1.440	1.356	0.436
13	FF	29	71	1.340	1.100	1.020	1.960	1.420	1.368	0.331
14	FF	37	63	0.440	0.380	1.280	1.080	1.060	0.848	0.366
$\bar{X}$	--	34	66	0.933	0.757	1.393	2.146	1.459	1.338	0.251
SD	--	5.8	5.8	0.460	0.268	0.314	0.667	0.246	0.553	0.268

Sub: Subject

RS: Running Style; FF: Forefoot; MF: Midfoot; HT: Heel-Toe

ST: Stance (percentage of gait cycle)
SW: Swing (percentage of gait cycle)

Sensor Sites: Units: kg/cm2

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE D23

Left EDG Surface: Concrete

Sub	RS	St	Sw	L	M	5	1	H	$\bar{X}$	SD
1	FF	40	60	1.660	1.080	1.740	1.740	0.820	1.408	0.384
2	FF	35	65	0.460	0.580	1.100	3.160	1.920	1.444	1.000
3	FF	27	73	0.520	0.380	1.500	3.300	1.540	1.448	1.043
4	FF	26	74	1.060	0.700	1.160	1.660	1.280	1.172	0.312
5	FF	38	62	1.280	0.760	1.680	3.160	1.940	1.764	0.804
6	HT	30	70	0.760	0.580	1.340	1.600	1.160	1.088	0.373
7	FF	26	74	0.760	0.400	1.960	0.460	1.480	1.012	0.610
8	FF	31	69	0.820	0.780	1.800	2.680	1.800	1.576	0.711
9	FF	40	60	1.100	1.060	1.660	1.880	1.600	1.460	0.324
10	HT	33	67	1.060	1.060	1.660	1.740	1.080	1.320	0.311
11	FF	39	61	1.100	1.500	1.960	3.600	1.600	1.952	0.868
12	MF	30	70	1.500	0.920	1.480	1.980	1.600	1.496	0.340
13	FF	36	64	1.540	1.160	1.160	2.020	1.500	1.476	0.316
14	FF	38	62	0.460	0.300	1.080	1.160	0.960	0.792	0.346
$\bar{X}$	--	33.5	66.5	1.006	0.804	1.520	2.153	1.449	1.386	0.288
SD	--	5.0	5.0	0.382	0.332	0.298	0.869	0.333	0.553	0.268

Sub: Subject

RS: Running Style; FF: Forefoot; MF: Midfoot; HT: Heel-Toe

ST: Stance (percentage of gait cycle)
SW: Swing (percentage of gait cycle)

Sensor Sites: Units: kg/cm2

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE D24
Left EDG   Surface: Grass

Sub	RS	St	Sw	L	M	5	1	H	$\bar{X}$	SD
1	FF	47	53	1.660	1.100	1.480	1.880	0.920	1.408	0.353
2	FF	26	74	0.580	0.620	0.820	2.820	1.880	1.344	0.877
3	MF	29	71	0.880	0.600	1.100	3.500	1.480	1.512	1.035
4	FF	32	68	0.960	0.760	1.340	1.800	1.500	1.272	0.373
5	MF	34	66	1.660	0.960	1.680	3.020	2.020	1.868	0.671
6	HT	32	68	0.820	0.520	1.080	1.600	1.080	1.020	0.356
7	MF	23	77	0.960	0.660	1.920	0.760	1.340	1.128	0.459
8	FF	32	68	1.040	0.820	1.540	2.820	1.740	1.592	0.698
9	FF	51	49	1.080	0.780	1.440	1.700	1.440	1.288	0.322
10	MF	37	63	0.820	0.780	1.100	1.660	1.280	1.128	0.323
11	FF	34	66	1.080	0.960	1.920	4.000	1.640	1.920	1.098
12	MF	30	70	1.660	1.060	1.080	2.020	1.500	1.464	0.363
13	FF	36	64	1.280	1.040	1.020	2.040	1.500	1.376	0.375
14	FF	38	62	0.740	0.560	0.960	1.040	0.960	0.852	0.177
$\bar{X}$	--	34.4	65.6	1.087	0.801	1.320	2.190	1.449	1.369	0.287
SD	--	7.2	7.2	0.340	0.188	0.340	0.887	0.309	0.534	0.280

Sub: Subject

RS: Running Style; FF: Forefoot; MF: Midfoot; HT: Heel-Toe

ST: Stance (percentage of gait cycle)
SW: Swing (percentage of gait cycle)

Sensor Sites: Units: kg/cm2

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE D25
Left EDG Surface: Asphalt

Sub	RS	St	Sw	L	M	5	1	H	$\bar{X}$	SD
1	FF	42	58	1.740	1.340	1.680	1.700	0.820	1.456	0.349
2	FF	40	60	0.660	0.680	1.220	3.020	1.680	1.452	0.870
3	FF	26	74	0.280	0.100	1.740	3.020	1.740	1.376	1.077
4	MF	26	74	0.920	0.660	1.080	1.660	1.220	1.108	0.333
5	FF	36	64	1.660	1.220	1.640	2.140	1.800	1.692	0.296
6	MF	30	70	0.600	0.500	1.080	1.680	1.220	1.016	0.430
7	MF	28	72	1.540	0.820	1.680	1.480	1.540	1.412	0.303
8	FF	32	68	0.500	0.500	1.600	2.820	1.740	1.432	0.870
9	FF	44	56	1.080	1.080	1.540	1.920	1.600	1.444	0.324
10	HT	28	72	1.100	0.960	1.420	1.500	1.280	1.252	0.199
11	FF	40	60	1.060	1.060	1.960	3.300	1.340	1.744	0.845
12	MF	30	70	1.080	0.760	1.640	1.940	1.340	1.352	0.413
13	HT	40	60	1.160	1.100	1.080	2.040	1.600	1.396	0.374
14	FF	40	60	0.820	0.680	0.880	0.760	1.040	0.836	0.122
$\bar{X}$	--	34.4	5.6	1.014	0.819	1.446	2.070	1.426	1.353	0.232
SD	--	6.2	6.2	0.415	0.321	0.310	0.696	0.282	0.486	0.286

Sub: Subject

RS: Running Style; FF: Forefoot; MF: Midfoot; HT: Heel-Toe

ST: Stance (percentage of gait cycle)
SW: Swing (percentage of gait cycle)

Sensor Sites: Units: kg/cm2

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux

$\bar{X}$: Mean
S.D.: Standard Deviation

APPENDIX E
TABLE E1
ANOVA TABLE

Right EDG Data - Lateral Calcaneal Region

Source	SS	df	MS	p
Surface	.206	4	.0516	.28
Error	2.032	52	.0391	
Total	2.238	56	--	

TABLE E2
ANOVA TABLE

Right EDG Data - Medial Calcaneal Region

Source	SS	df	MS	p
Surface	.772	4	.1930	.03a
Error	3.450	52	.0664	
Total	4.222	56	--	

a: $p \leq .10$

TABLE E3
ANOVA TABLE

Right EDG Data - First Metatarsal

Source	SS	df	MS	p
Surface	.102	4	.0254	.57
Error	1.798	52	.0346	
Total	1.900	56	--	

TABLE E4
ANOVA TABLE

Right EDG Data - Fifth Metatarsal

Source	SS	df	MS	p
Surface	.270	4	.0675	.20*
Error	2.146	52	.0413	
Total	2.416	56	--	

*Huynh-Feldt Probability

TABLE E5
ANOVA TABLE

Right EDG Data - Hallux

Source	SS	df	MS	p
Surface	.076	4	.0191	.59*
Error	1.851	52	.0356	
Total	1.927	56	--	

*Huynh-Feldt Probability

TABLE E6
2X2 ANOVA TABLE

Right EDG Data

Source	SS	df	MS	p
Surface	.15527	4	.0388	.66
Error	3.29916	52		
Sensor	42.33851	4	10.5840	.00a*
Error	36.33990	52	.6988	
Surface X Sensor	1.27083	16	.0794	.01a*
Error	7.97730	208	.0384	
Total	91.37800	336	--	--

a: $p \leq .10$
*Huynh-Feldt Probability

APPENDIX E

TABLE E7

Right EDG Subject:1

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	HT	HT	HT	HT	HT		
Stance	29	27	31	28	27	28.4	1.497
Swing	71	73	69	72	73	71.6	1.497
L	1.280	1.480	1.500	1.340	1.600	1.440	0.115
M	1.160	1.080	1.440	1.080	1.100	1.172	0.137
5	1.920	1.920	2.140	1.880	2.140	2.000	0.115
1	1.660	1.600	1.700	2.020	1.960	1.788	0.169
H	1.980	1.920	1.960	1.880	1.960	1.940	0.036
$\bar{X}$	1.600	1.600	1.748	1.640	1.752	1.668	0.069
SD	0.331	0.313	0.267	0.364	0.370	0.329	0.037

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE E8
Right EDG Subject:2

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	MF	FF	FF	FF	MF		
Stance	26	26	26	30	25	26.6	1.744
Swing	74	74	74	70	75	73.4	1.744
L	0.860	0.380	0.480	0.460	0.520	0.540	0.166
M	1.280	0.480	0.920	0.760	0.860	0.860	0.259
5	3.020	2.820	2.600	2.440	2.820	2.740	0.200
1	2.140	2.600	2.140	2.000	2.140	2.204	0.205
H	2.680	2.040	1.940	1.940	1.960	2.112	0.286
$\bar{X}$	1.996	1.664	1.528	1.520	1.660	1.674	0.173
SD	0.817	1.040	0.921	0.769	0.849	0.879	0.094

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE E9

Right EDG Subject:3

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	MF	MF	MF	FF	MF		
Stance	28	29	30	28	28	28.6	0.800
Swing	72	71	70	72	72	71.4	0.800
L	0.700	0.700	0.480	1.060	1.080	0.804	0.232
M	0.580	0.420	0.400	0.620	0.580	0.520	0.091
5	2.820	2.600	2.680	2.040	2.600	2.548	0.266
1	3.160	2.600	2.140	3.160	2.600	2.732	0.388
H	2.000	1.920	1.940	1.920	2.020	1.960	0.042
$\bar{X}$	1.964	1.648	1.528	1.760	1.776	1.7352	0.145
SD	0.863	0.927	0.921	0.878	0.816	0.881	0.041

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE E10
Right EDG Subject:4

RS	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
	HT	HT	HT	HT	HT		
Stance	29	25	26	25	30	27	2.098
Swing	71	75	74	75	70	73	2.098
L	0.880	0.620	0.920	0.920	1.020	0.872	0.134
M	1.100	0.760	1.540	1.420	1.660	1.296	0.327
5	1.220	1.500	1.220	1.420	1.280	1.328	0.113
1	0.920	1.080	1.100	1.100	1.100	1.060	0.070
H	1.080	1.100	1.100	1.040	1.100	1.084	0.023
$\bar{X}$	1.040	1.012	1.176	1.180	1.232	1.128	0.086
SD	0.125	0.306	0.206	0.204	0.230	0.214	0.058

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE E11
Right EDG   Subject:5

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	HT	HT	HT	HT	HT		
Stance	29	29	25	28	28	27.8	1.470
Swing	71	71	75	72	72	72.2	1.470
L	1.600	1.680	1.060	1.600	1.640	1.516	0.230
M	1.920	1.920	1.680	1.740	1.940	1.840	0.108
5	1.740	1.880	1.920	1.880	1.660	1.816	0.099
1	1.800	1.740	1.980	1.880	1.880	1.856	0.081
H	1.440	1.740	2.140	2.020	1.980	1.864	0.249
$\bar{X}$	1.700	1.792	1.756	1.824	1.820	1.778	0.046
SD	0.166	0.092	0.378	0.143	0.143	0.184	0.100

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE E12
Right EDG Subject:6

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	MF	MF	MF	FF	MF		
Stance	26	35	29	30	28	29.6	3.007
Swing	74	65	71	70	72	71.4	3.007
L	0.380	0.440	0.560	0.580	0.260	0.444	0.118
M	0.300	0.420	0.620	0.920	0.300	0.512	0.235
5	1.960	1.680	1.600	1.600	1.700	1.708	0.132
1	1.660	1.680	1.740	1.440	1.660	1.636	0.102
H	1.880	1.060	1.080	1.080	1.040	1.228	0.326
$\bar{X}$	1.236	1.056	1.120	1.124	0.992	1.106	0.081
SD	0.739	0.560	0.486	0.365	0.627	0.555	0.126

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE E13
Right EDG   Subject:7

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	FF	HT	MF	HT	HT		
Stance	40	26	27	32	25	30.0	5.550
Swing	60	74	73	68	75	70.0	5.550
L	0.780	1.020	0.500	1.020	1.100	0.884	0.220
M	0.660	1.160	0.380	1.540	1.600	1.068	0.480
5	3.160	2.820	2.440	1.960	2.600	2.596	0.399
1	1.920	1.920	1.920	1.960	1.740	1.892	0.078
H	1.920	1.880	1.660	1.340	1.700	1.700	0.206
$\bar{X}$	1.688	1.760	1.380	1.564	1.748	1.628	0.142
SD	0.912	0.644	0.809	0.363	0.484	0.642	0.202

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE E14
Right EDG Subject:8

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	FF	FF	FF	FF	FF		
Stance	30	47	47	43	49	43.2	6.882
Swing	70	53	53	57	51	56.8	6.882
L	0.400	0.420	1.080	1.080	0.680	0.732	0.301
M	0.460	0.440	1.080	1.220	0.740	0.788	0.317
5	1.700	2.040	1.960	1.880	1.920	1.900	0.113
1	2.000	1.940	2.000	1.960	1.940	1.968	0.027
H	1.740	1.680	1.740	1.700	1.660	1.704	0.032
$\bar{X}$	1.260	1.304	1.572	1.568	1.388	1.418	0.130
SD	0.686	0.723	0.411	0.354	0.563	0.547	0.146

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE E15
Right EDG Subject:9

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	HT	HT	HT	HT	HT		
Stance	28	29	30	30	33	30.0	1.673
Swing	72	71	70	70	67	70.0	1.673
L	1.600	1.440	1.340	1.340	1.600	1.464	0.117
M	1.160	1.680	1.540	1.800	1.600	1.556	0.216
5	1.100	1.540	1.440	1.340	1.540	1.392	0.164
1	1.220	1.080	1.340	1.340	1.340	1.264	0.103
H	1.280	1.080	1.080	1.060	1.100	1.120	0.081
$\bar{X}$	1.272	1.364	1.348	1.376	1.436	1.359	0.053
SD	0.175	0.244	0.153	0.238	0.193	0.201	0.035

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE E16
Right EDG Subject:10

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	MF	MF	HT	FF	MF		
Stance	28	27	27	29	28	27.8	0.748
Swing	72	73	73	71	72	72.2	0.748
L	0.760	0.580	0.760	0.500	0.620	0.644	0.102
M	1.480	1.100	1.280	1.280	1.100	1.248	0.141
5	1.660	1.880	1.640	1.940	1.680	1.760	0.125
1	1.600	1.340	1.540	1.340	1.280	1.420	0.126
H	1.040	1.420	1.040	1.660	1.100	1.252	0.248
$\bar{X}$	1.308	1.264	1.252	1.344	1.156	1.265	0.064
SD	0.350	0.425	0.323	0.484	0.342	0.385	0.061

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE E17
Right EDG Subject:11

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	MF	MF	MF	FF	FF		
Stance	31	29	32	39	39	34.0	4.195
Swing	69	71	68	61	61	66.0	4.195
L	0.820	1.080	1.420	1.060	0.820	1.040	0.221
M	0.960	1.280	1.680	1.440	1.060	1.284	0.259
5	1.660	1.740	1.700	1.680	1.740	1.704	0.032
1	2.040	2.140	2.440	2.600	2.020	2.248	0.231
H	1.680	1.800	1.880	1.740	1.700	1.760	0.073
$\bar{X}$	1.432	1.608	1.824	1.704	1.468	1.607	0.146
SD	0.465	0.380	0.341	0.508	0.451	0.429	0.060

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE E18
Right EDG Subject:12

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	HT	HT	HT	HT	HT		
Stance	26	28	31	27	27	27.8	1.721
Swing	74	72	69	73	73	72.2	1.721
L	0.660	0.820	0.820	0.820	0.780	0.780	0.062
M	0.920	0.860	0.780	0.920	0.660	0.828	0.099
5	1.100	0.780	0.700	0.760	0.760	0.820	0.143
1	1.040	0.760	0.820	0.820	0.820	0.852	0.097
H	0.780	0.700	0.780	0.860	0.760	0.776	0.051
$\bar{X}$	0.900	0.784	0.780	0.836	0.756	0.811	0.052
SD	0.162	0.054	0.044	0.053	0.053	0.073	0.045

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE E19
Right EDG Subject:13

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	FF	FF	FF	MF	FF		
Stance	34	32	33	28	39	33.2	3.544
Swing	66	68	67	72	61	66.8	3.544
L	0.880	0.780	1.100	0.960	1.160	0.976	0.139
M	1.260	1.340	1.660	1.600	1.640	1.500	0.166
5	1.440	1.540	1.880	1.700	1.880	1.688	0.177
1	1.760	1.680	1.500	1.480	1.500	1.584	0.114
H	1.620	1.440	1.640	1.700	1.600	1.600	0.087
$\bar{X}$	1.392	1.356	1.556	1.488	1.556	1.470	0.083
SD	0.306	0.309	0.258	0.276	0.234	0.277	0.029

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE E20
Right EDG Subject:14

	Tar	Cin	Con	Grs	Asp	$\bar{X}$	S.D.
RS	MF	HT	HT	HT	HT		
Stance	29	28	30	31	30	29.6	1.020
Swing	71	72	70	69	70	70.4	1.020
L	0.620	0.700	0.740	1.060	1.040	0.832	0.182
M	0.420	0.480	0.480	1.060	0.960	0.680	0.272
5	1.480	1.100	1.660	1.080	1.220	1.380	0.227
1	1.600	1.340	1.280	1.220	1.100	1.308	0.166
H	1.540	1.640	1.660	1.700	1.740	1.656	0.067
$\bar{X}$	1.132	1.052	1.164	1.224	1.212	1.157	0.062
SD	0.505	0.420	0.480	0.245	0.277	0.385	0.106

RS: Running Style; FF: Forefoot, MF: Midfoot; HT: Heel-Toe

Stance: percentage of gait cycle
Swing: percentage of gait cycle

Sensor Sites:

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux (Great Toe)

Surfaces:

Tar: Tartan
Cin: Cinders
Con: Concrete
Grs: Grass
Asp: Asphalt

Units: kg/cm2

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE E21
Right EDG Surface: Tartan

Sub	RS	St	Sw	L	M	5	1	H	$\bar{X}$	SD
1	HT	29	71	1.280	1.160	1.920	1.660	1.980	1.600	0.331
2	MF	26	74	0.860	1.280	3.020	2.140	2.680	1.996	0.817
3	MF	28	72	0.700	0.580	2.820	3.160	2.000	1.964	0.863
4	HT	29	71	0.880	1.100	1.220	0.920	1.080	1.040	0.125
5	HT	29	71	1.600	1.920	1.740	1.800	1.440	1.700	0.166
6	MF	26	74	0.380	0.300	1.960	1.660	1.880	1.236	0.739
7	FF	40	60	0.780	0.660	3.160	1.920	1.920	1.688	0.912
8	FF	30	70	0.400	0.460	1.700	2.000	1.740	1.260	0.686
9	HT	28	72	1.600	1.160	1.100	1.220	1.280	1.272	0.175
10	MF	28	72	0.760	1.480	1.660	1.600	1.040	1.308	0.350
11	MF	31	69	0.820	0.960	1.660	2.040	1.680	1.432	0.465
12	HT	26	74	0.660	0.920	1.100	1.040	0.780	0.900	0.162
13	FF	34	66	0.880	1.260	1.440	1.760	1.620	1.392	0.306
14	MF	29	71	0.620	0.420	1.480	1.600	1.540	1.132	0.505
$\bar{X}$	--	30	70	0.873	0.976	1.856	1.751	1.619	1.423	0.317
SD	--	3.6	3.6	0.364	0.439	0.653	0.525	0.468	0.460	0.279

Sub: Subject

RS: Running Style; FF: Forefoot; MF: Midfoot; HT: Heel-Toe

ST: Stance (percentage of gait cycle)
SW: Swing (percentage of gait cycle)

Sensor Sites: Units: kg/cm2

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE E22

Right EDG Surface: Cinders

Sub	RS	St	Sw	L	M	5	1	H	$\bar{X}$	SD
1	HT	27	73	1.480	1.080	1.920	1.600	1.920	1.600	0.313
2	FF	26	74	0.380	0.480	2.820	2.600	2.040	1.664	1.040
3	MF	29	71	0.700	0.420	2.600	2.600	1.920	1.648	0.927
4	HT	25	75	0.620	0.760	1.500	1.080	1.100	1.012	0.306
5	HT	29	71	1.680	1.920	1.880	1.740	1.740	1.792	0.092
6	MF	35	65	0.440	0.420	1.680	1.680	1.060	1.056	0.560
7	HT	26	74	1.020	1.160	2.820	1.920	1.880	1.760	0.644
8	FF	47	53	0.420	0.440	2.040	1.940	1.680	1.304	0.723
9	HT	29	71	1.440	1.680	1.540	1.080	1.080	1.364	0.244
10	MF	27	73	0.580	1.100	1.880	1.340	1.420	1.264	0.425
11	MF	29	71	1.080	1.280	1.740	2.140	1.800	1.608	0.380
12	HT	28	72	0.820	0.860	0.780	0.760	0.700	0.784	0.054
13	FF	32	68	0.780	1.340	1.540	1.680	1.440	1.356	0.309
14	HT	28	72	0.700	0.480	1.100	1.340	1.640	1.052	0.420
$\bar{X}$	--	29.8	70.2	0.867	0.959	1.846	1.679	1.530	1.374	0.306
SD	--	5.37	5.37	0.402	0.473	0.570	0.524	0.392	0.460	0.279

Sub: Subject

RS: Running Style; FF: Forefoot; MF: Midfoot; HT: Heel-Toe

ST: Stance (percentage of gait cycle)
SW: Swing (percentage of gait cycle)

Sensor Sites: Units: kg/cm2

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux

$\bar{x}$: Mean
S.D.: Standard Deviation

TABLE E23

Right EDG Surface: Concrete

Sub	RS	St	Sw	L	M	5	1	H	$\bar{X}$	SD
1	HT	31	69	1.500	1.440	2.140	1.700	1.960	1.748	0.267
2	FF	26	74	0.480	0.920	2.600	2.140	1.940	1.616	0.790
3	MF	30	70	0.480	0.400	2.680	2.140	1.940	1.528	0.921
4	HT	26	74	0.920	1.540	1.220	1.100	1.100	1.176	0.206
5	HT	25	75	1.060	1.680	1.920	1.980	2.140	1.756	0.378
6	MF	29	71	0.560	0.620	1.600	1.740	1.080	1.120	0.486
7	MF	27	73	0.500	0.380	2.440	1.920	1.660	1.380	0.809
8	FF	47	53	1.080	1.080	1.960	2.000	1.740	1.572	0.411
9	HT	30	70	1.340	1.540	1.440	1.340	1.080	1.348	0.153
10	HT	27	73	0.760	1.280	1.640	1.540	1.040	1.252	0.323
11	MF	32	68	1.420	1.680	1.700	2.440	1.880	1.824	0.341
12	HT	31	69	0.820	0.780	0.700	0.820	0.780	0.780	0.044
13	FF	33	67	1.100	1.660	1.880	1.500	1.640	1.556	0.258
14	HT	30	70	0.740	0.480	1.660	1.280	1.660	1.164	0.480
$\bar{X}$	--	30.3	69.7	**0.911**	**1.106**	**1.827**	**1.689**	**1.546**	**1.416**	**0.285**
SD	--	5.2	5.2	0.338	0.484	0.517	0.436	0.422	0.419	0.250

Sub: Subject

RS: Running Style; FF: Forefoot; MF: Midfoot; HT: Heel-Toe

ST: Stance (percentage of gait cycle)
SW: Swing (percentage of gait cycle)

Sensor Sites: Units: kg/cm2

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE E24
Right EDG   Surface: Grass

Sub	RS	St	Sw	L	M	5	1	H	$\bar{X}$	SD
1	HT	28	72	1.340	1.080	1.880	2.020	1.880	1.640	0.364
2	FF	30	70	0.460	0.760	2.440	2.000	1.940	1.520	0.769
3	FF	28	72	1.060	0.620	2.040	3.160	1.920	1.760	0.878
4	HT	25	75	0.920	1.420	1.420	1.100	1.040	1.180	0.204
5	HT	28	72	1.600	1.740	1.880	1.880	2.020	1.824	0.143
6	FF	30	70	0.580	0.920	1.600	1.440	1.080	1.124	0.365
7	HT	32	68	1.020	1.540	1.960	1.960	1.340	1.564	0.363
8	FF	43	57	1.080	1.220	1.880	1.960	1.700	1.568	0.354
9	HT	30	70	1.340	1.800	1.340	1.340	1.060	1.376	0.238
10	FF	29	71	0.500	1.280	1.940	1.340	1.660	1.344	0.484
11	FF	39	61	1.060	1.440	1.680	2.600	1.740	1.704	0.508
12	HT	27	73	0.820	0.920	0.760	0.820	0.860	0.836	0.053
13	MF	28	72	0.960	1.600	1.700	1.480	1.700	1.488	0.276
14	HT	31	69	1.060	1.060	1.080	1.220	1.700	1.224	0.245
$\bar{X}$	--	30.6	69.4	0.986	1.243	1.686	1.737	1.546	1.439	0.266
SD	--	4.6	4.6	0.312	0.352	0.411	0.599	0.376	0.375	0.219

Sub: Subject

RS: Running Style; FF: Forefoot; MF: Midfoot; HT: Heel-Toe

ST: Stance (percentage of gait cycle)
SW: Swing (percentage of gait cycle)

Sensor Sites: Units: kg/cm2

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux

$\bar{X}$: Mean
S.D.: Standard Deviation

TABLE E25
Right EDG Surface: Asphalt

Sub	RS	St	Sw	L	M	5	1	H	$\tilde{X}$	SD
1	HT	27	73	1.600	1.100	2.140	1.960	1.960	1.752	0.370
2	MF	25	75	0.520	0.860	2.820	2.140	1.960	1.660	0.849
3	MF	28	72	1.080	0.580	2.600	2.600	2.020	1.776	0.816
4	HT	30	70	1.020	1.660	1.280	1.100	1.100	1.232	0.230
5	HT	28	72	1.640	1.940	1.660	1.880	1.980	1.820	0.143
6	MF	28	72	0.260	0.300	1.700	1.660	1.040	0.992	0.627
7	HT	25	75	1.100	1.600	2.600	1.740	1.700	1.748	0.484
8	FF	49	51	0.680	0.740	1.920	1.940	1.660	1.388	0.563
9	HT	33	67	1.600	1.600	1.540	1.340	1.100	1.436	0.193
10	MF	28	72	0.620	1.100	1.680	1.280	1.100	1.156	0.342
11	FF	39	61	0.820	1.060	1.740	2.020	1.700	1.468	0.451
12	HT	27	73	0.780	0.660	0.760	0.820	0.760	0.756	0.053
13	FF	39	61	1.160	1.640	1.880	1.500	1.600	1.556	0.234
14	HT	30	70	1.040	0.960	1.220	1.100	1.740	1.212	0.277
$\bar{X}$	--	31.1	68.9	0.994	1.129	1.824	1.649	1.530	1.425	0.311
SD	--	6.5	6.5	0.403	0.472	0.551	0.468	0.407	0.402	0.234

Sub: Subject

RS: Running Style; FF: Forefoot; MF: Midfoot; HT: Heel-Toe

ST: Stance (percentage of gait cycle)
SW: Swing (percentage of gait cycle)

Sensor Sites: Units: kg/cm2

L: Lateral Calcaneal Region
M: Medial Calcaneal Region
5: Fifth Metatarsal
1: First Metatarsal
H: Hallux

$\bar{x}$: Mean
S.D.: Standard Deviation

APPENDIX F
TABLE F1
ANOVA TABLE

Kinematic Data - Stride Length

Source	SS	df	MS	p
Surface	.211	4	.0527	.52
Error	2.826	44	.0642	
Total	3.087	48	--	

TABLE F2
ANOVA TABLE

Kinematic Data - Stride Rate

Source	SS	df	MS	p
Surface	.014	4	.0034	.06a
Error	.061	44	.0014	
Total	.075	48	--	

a: $p \leq .10$

TABLE F3
ANOVA TABLE

Kinematic Data - Single Leg Support Time

Source	SS	df	MS	p
Surface	9.886	4	2.472	.65
Error	173.957	44	3.954	
Total	183.843	48	--	

TABLE F4
ANOVA TABLE

Kinematic Data - Swing Time

Source	SS	df	MS	p
Surface	9.886	4	2.472	.65
Error	173.957	44	3.954	
Total	183.843	48	--	

TABLE F5
ANOVA TABLE

Kinematic Data - Speed

Source	SS	df	MS	p
Surface	.824	4	.2061	.24
Error	6.382	44	.1451	
Total	7.206	48	--	

APPENDIX F

TABLE F6
Running Kinematic Data

Subject: 1

Surface	SL	SR	SLS	SW	SP
Tar	3.85	1.49	32.84	67.16	5.74
Asp	3.60	1.52	33.34	66.66	5.47
Con	3.61	1.47	30.88	69 12	5.31
Grs	3.92	1.47	35.29	64.71	5.76
Cin	3.38	1.47	30.88	69.12	4.97
$\bar{X}$	3.67	1.48	32.65	67.35	5.45
SD	0.194	0.020	1.658	1.658	0.294

Subject: 2

Surface	SL	SR	SLS	SW	SP
Tar	3.46	1.56	25.00	75.00	5.40
Asp	3.63	1.54	27.69	72.31	5.59
Con	3.81	1.49	25.37	74.63	5.68
Grs	3.53	1.52	30.30	69.70	5.37
Cin	3.60	1.56	28.13	71.87	5.62
$\bar{X}$	3.61	1.53	27.30	72.70	5.532
SD	0.118	0.027	1.942	1.942	0.124

Tar: Tartan
Asp: Asphalt
Con: Concrete
Grs: Grass
Cin: Cinders

Kinematics:	Units:
SL: Stride Length	meters
SR: Stride Rate	# of strides/second
SLS: Single Leg Support Time	percentage of gait cycle
SW: Swing Time	percentage of gait cycle
SP: Speed	meters/second

TABLE F7
Running Kinematic Data

Subject: 3

Surface	SL	SR	SLS	SW	SP
Tar	3.74	1.41	23.94	76.06	5.27
Asp	3.45	1.45	26.09	73.91	5.01
Con	3.34	1.42	28.57	71.43	4.78
Grs	3.68	1.37	31.51	68.49	5.04
Cin	3.61	1.39	30.56	69.44	5.02
$\bar{X}$	3.56	1.41	28.13	71.87	5.024
SD	0.148	0.028	2.801	2.801	0.155

Subject: 4

Surface	SL	SR	SLS	SW	SP
Tar	3.77	1.43	25.71	74.29	5.39
Asp	3.93	1.43	27.14	72.86	5.62
Con	3.78	1.43	27.14	70.83	5.25
Grs	4.03	1.41	26.76	73.24	5.64
Cin	4.0	1.41	26.76	73.24	5.64
$\bar{X}$	3.90	1.41	27.59	72.41	5.50
SD	0.109	0.018	1.372	1.372	0.154

Tar: Tartan
Asp: Asphalt
Con: Concrete
Grs: Grass
Cin: Cinders

Kinematics:	Units:
SL: Stride Length	meters
SR: Stride Rate	# of strides/second
SLS: Single Leg Support Time	percentage of gait cycle
SW: Swing Time	percentage of gait cycle
SP: Speed	meters/second

TABLE F8
Running Kinematic Data

Subject: 5

Surface	SL	SR	SLS	SW	SP
Tar	3.42	1.41	26.76	73.24	4.82
Asp	3.65	1.47	29.41	70.59	5.37
Con	3.84	1.49	29.85	70.15	5.72
Grs	3.78	1.43	27.14	72.86	5.41
Cin	3.36	1.47	26.47	73.53	4.94
$\bar{X}$	3.61	1.45	27.93	72.67	5.25
SD	0.191	0.029	1.414	1.414	0.329

Subject: 6

Surface	SL	SR	SLS	SW	SP
Tar	3.55	1.43	30.00	70.00	5.08
Asp	4.05	1.52	28.79	71.21	6.12
Con	3.18	1.41	32.39	67.61	4.48
Grs	3.45	1.49	26.87	73.13	5.14
Cin	3.41	1.49	31.34	68.66	5.08
$\bar{X}$	3.53	1.47	29.88	70.12	5.18
SD	0.288	0.041	1.934	1.934	0.528

Tar: Tartan
Asp: Asphalt
Con: Concrete
Grs: Grass
Cin: Cinders

Kinematics:	Units:
SL: Stride Length	meters
SR: Stride Rate	# of strides/second
SLS: Single Leg Support Time	percentage of gait cycle
SW: Swing Time	percentage of gait cycle
SP: Speed	meters/second

TABLE F9
Running Kinematic Data

Subject: 7

Surface	SL	SR	SLS	SW	SP
Tar	3.71	1.45	27.54	72.46	5.38
Asp	3.58	1.34	24.00	76.00	4.80
Con	3.59	1.35	24.32	75.68	4.85
Grs	3.68	1.39	27.78	72.22	5.12
Cin	3.87	1.41	29.58	70.42	5.46
$\bar{X}$	3.69	1.39	26.64	73.36	5.12
SD	0.105	0.040	2.150	2.150	0.268

Subject: 8

Surface	SL	SR	SLS	SW	SP
Tar	4.84	1.39	25.00	75.00	6.73
Asp	4.54	1.30	24.68	75.32	5.90
Con	4.36	1.28	24.36	75.64	5.58
Grs	3.50	1.39	26.39	73.61	4.87
Cin	3.94	1.35	29.73	70.27	5.32
$\bar{X}$	4.24	1.34	26.03	73.97	5.68
SD	0.470	0.045	1.974	1.974	0.624

Tar: Tartan
Asp: Asphalt
Con: Concrete
Grs: Grass
Cin: Cinders

Kinematics:	Units:
SL: Stride Length	meters
SR: Stride Rate	# of strides/second
SLS: Single Leg Support Time	percentage of gait cycle
SW: Swing Time	percentage of gait cycle
SP: Speed	meters/second

TABLE F10
Running Kinematic Data

Subject: 9

Surface	SL	SR	SLS	SW	SP
Tar	3.17	1.49	32.83	67.17	4.72
Asp	3.05	1.45	31.88	68.12	4.42
Con	2.95	1.47	29.41	70.59	4.34
Grs	3.26	1.43	31.43	68.57	4.66
Cin	3.05	1.47	30.88	69.12	4.48
$\bar{X}$	3.10	1.46	31.29	68.71	4.52
SD	0.108	0.020	1.135	1.135	0.144

Subject: 10

Surface	SL	SR	SLS	SW	SP
Tar	2.55	1.39	30.56	69.44	3.55
Asp	2.51	1.32	28.95	71.05	3.31
Con	2.60	1.34	28.00	72.00	3.48
Grs	2.73	1.43	25.71	74.29	3.90
Cin	3.07	1.37	30.14	69.86	4.21
$\bar{X}$	2.69	1.37	28.67	71.33	3.69
SD	0.203	0.039	1.733	1.733	0.323

Tar: Tartan
Asp: Asphalt
Con: Concrete
Grs: Grass
Cin: Cinders

Kinematics:	Units:
SL: Stride Length	meters
SR: Stride Rate	# of strides/second
SLS: Single Leg Support Time	percentage of gait cycle
SW: Swing Time	percentage of gait cycle
SP: Speed	meters/second

TABLE F11
Running Kinematic Data

Subject: 11

Surface	SL	SR	SLS	SW	SP
Tar	3.30	1.43	31.43	68.57	4.72
Asp	3.26	1.39	31.94	68.06	4.53
Con	3.24	1.41	33.80	66.20	4.57
Grs	3.14	1.43	32.86	67.14	4.49
Cin	3.17	1.45	30.43	69.57	4.60
$\bar{X}$	3.22	1.42	32.09	67.91	4.582
SD	0.059	0.020	1.160	1.160	0.078

Subject: 12

Surface	SL	SR	SLS	SW	SP
Tar	4.20	1.54	29.23	70.77	6.47
Asp	3.64	1.45	28.99	71.01	5.28
Con	3.48	1.41	28.17	71.83	4.91
Grs	3.81	1.49	28.36	71.64	5.68
Cin	3.18	1.59	26.98	73.02	5.06
$\bar{X}$	3.66	1.496	28.35	71.65	5.48
SD	0.340	0.064	0.787	0.787	0.559

Tar: Tartan
Asp: Asphalt
Con: Concrete
Grs: Grass
Cin: Cinders

Kinematics:	Units:
SL: Stride Length	meters
SR: Stride Rate	# of strides/second
SLS: Single Leg Support Time	percentage of gait cycle
SW: Swing Time	percentage of gait cycle
SP: Speed	meters/second

TABLE F12
Running Kinematic Data

Surface: Tartan

Subject	SL	SR	SLS	SW	SP
1	3.85	1.49	32.84	67.16	5.74
2	3.46	1.56	25.00	75.00	5.40
3	3.74	1.41	23.94	76.06	5.27
4	3.77	1.43	25.71	74.29	5.39
5	3.42	1.41	26.76	73.24	4.82
6	3.55	1.43	30.00	70.00	5.08
7	3.71	1.45	27.54	72.46	5.38
8	4.84	1.39	25.00	75.00	6.73
9	3.17	1.49	32.83	67.17	4.72
10	2.55	1.39	30.56	69.44	3.55
12	3.30	1.43	31.43	68.57	4.72
13	4.20	1.54	29.23	70.77	6.47
N=12					
X	3.63	1.45	28.40	71.60	5.27
S.D.	0.536	0.054	3.029	3.029	0.798

Kinematics:	Units:
SL: Stride Length	meters
SR: Stride Rate	# of strides/second
SLS: Single Leg Support Time	percentage of gait cycle
SW: Swing Time	percentage of gait cycle
SP: Speed	meters/second

TABLE F13
Running Kinematic Data

Surface: Cinders

Subject	SL	SR	SLS	SW	SP
1	3.38	1.47	30.88	69.12	4.97
2	3.60	1.56	28.13	71.87	5.62
3	3.61	1.39	30.56	69.44	5.02
4	4.00	1.41	26.76	73.24	5.64
5	3.36	1.47	26.47	73.53	4.94
6	3.41	1.49	31.34	68.66	5.08
7	3.87	1.41	29.58	70.42	5.46
8	3.94	1.35	29.73	70.27	5.32
9	3.05	1.47	30.88	69.12	4.48
10	3.07	1.37	30.14	69.86	4.21
12	3.17	1.45	30.43	69.57	4.60
13	3.18	1.59	26.98	73.02	5.06
N=12					
$\bar{X}$	3.47	1.45	29.32	70.68	5.03
S.D.	0.321	0.069	1.688	1.688	0.425

Kinematics:	Units:
SL: Stride Length	meters
SR: Stride Rate	# of strides/second
SLS: Single Leg Support Time	percentage of gait cycle
SW: Swing Time	percentage of gait cycle
SP: Speed	meters/second

TABLE F14
Running Kinematic Data

Surface: Concrete

Subject	SL	SR	SLS	SW	SP
1	3.61	1.47	30.88	69.12	5.31
2	3.81	1.49	25.37	74.63	5.68
3	3.34	1.43	28.57	71.43	4.78
4	3.78	1.39	29.17	70.83	5.25
5	3.84	1.49	29.85	70.15	5.72
6	3.18	1.41	32.39	67.61	4.48
7	3.59	1.35	24.32	75.68	4.85
8	4.36	1.28	24.36	75.64	5.58
9	2.95	1.47	29.41	70.59	4.34
10	2.60	1.34	28.00	72.00	3.48
12	3.24	1.41	33.80	66.20	4.57
13	3.48	1.41	28.17	71.83	4.91
N=12					
$\bar{X}$	3.48	1.41	28.69	71.31	4.91
S.D.	0.443	0.062	2.833	2.833	0.623

Kinematics:	Units:
SL: Stride Length	meters
SR: Stride Rate	# of strides/second
SLS: Single Leg Support Time	percentage of gait cycle
SW: Swing Time	percentage of gait cycle
SP: Speed	meters/second

TABLE F15
Running Kinematic Data

Surface: Grass

Subject	SL	SR	SLS	SW	SP
1	3.92	1.47	35.29	64.71	5.76
2	3.53	1.52	30.30	69.70	5.37
3	3.68	1.37	31.51	68.49	5.04
4	4.03	1.39	29.17	70.83	5.60
5	3.78	1.43	27.14	72.86	5.41
6	3.45	1.49	26.87	73.13	5.14
7	3.68	1.39	27.78	72.22	5.12
8	3.50	1.39	26.39	73.61	4.87
9	3.26	1.43	31.43	68.57	4.66
10	2.73	1.43	25.71	74.29	3.90
12	3.14	1.43	32.86	67.14	4.49
13	3.81	1.49	28.36	71.64	5.68
N=12					
$\bar{X}$	3.54	1.44	29.40	70.60	5.09
S.D.	0.348	0.456	2.799	2.799	0.521

Kinematics:	Units:
SL: Stride Length	meters
SR: Stride Rate	# of strides/second
SLS: Single Leg Support Time	percentage of gait cycle
SW: Swing Time	percentage of gait cycle
SP: Speed	meters/second

TABLE F16
Running Kinematic Data

Surface: Asphalt

Subject	SL	SR	SLS	SW	SP
1	3.60	1.52	33.34	66.66	5.47
2	3.63	1.54	27.69	72.31	5.59
3	3.45	1.45	26.09	73.91	5.01
4	3.93	1.43	27.14	72.86	5.62
5	3.65	1.47	29.41	70.59	5.37
6	4.05	1.52	28.79	71.21	6.12
7	3.58	1.34	24.00	76.00	4.80
8	4.54	1.30	24.68	75.32	5.90
9	3.05	1.45	31.88	68.12	4.42
10	2.51	1.32	28.95	71.05	3.31
12	3.26	1.39	31.94	68.06	4.53
13	3.64	1.45	28.99	71.01	5.28
N=12					
$\bar{X}$	3.57	1.43	28.58	71.42	5.12
S.D.	0.485	0.076	2.756	2.756	0.737

Kinematics:	Units:
SL: Stride Length	meters
SR: Stride Rate	# of strides/second
SLS: Single Leg Support Time	percentage of gait cycle
SW: Swing Time	percentage of gait cycle
SP: Speed	meters/second