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Shock attenuation and impact characteristics for children running at different stride lengths

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SHOCK ATTENUATION AND IMPACT CHARACTERISTICS FOR CHILDREN
RUNNING AT DIFFERENT STRIDE LENGTHS

by

Kunal Bhanot

Bachelor in Physiotherapy
Guru Nanak Dev University, India
2004

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science Degree in Kinesiology
Department of Kinesiology
School of Allied Health Sciences
Division of Health Sciences

Graduate College
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Thesis Approval
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Entitled

Shock Attenuation and Impact Characteristics for Children

Running at Different Stride Lengths

is approved in partial fulfillment of the requirements for the degree of

Master of Science in Kinesiology

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ABSTRACT

Shock Attenuation and Impact Characteristics for Children Running at Different Stride Lengths

By

Kunal Bhanot

John A. Mercer, Ph.D., Examination Committee Chair
Associate Professor of Kinesiology
University of Nevada, Las Vegas

The purpose of this study was to quantify shock attenuation (SA) and impact characteristics for children (boys and girls) running with different stride lengths (SL). Ten physically active children (10.7 ± 1.1 yrs; 40 ± 10.3 kg; 145.2 ± 7.3 cm) ran at a constant speed of $3\text{m/s} \pm 5\%$ range to complete three stride length conditions: Preferred stride length (PSL), -15% PSL and $+15\%$ PSL. During PSL, participants were given no instructions regarding stride length. During -15% PSL and $+15\%$ PSL, participants were required to strike markers placed on the floor that resulted in stride length of -15% and $+15\%$ of PSL. Ground reaction forces were recorded (1008 Hz) using a force plate (Kistler Instrument) that was mounted flush with the floor in the middle of a 20m runway. Accelerometers (1008 Hz) were securely mounted on the distal aspect of the tibia and on frontal aspect of the forehead. Impact force and shock attenuation in time and frequency domain (calculated as the ratio of head and leg impact accelerations and ratio of power spectral density of head and leg acceleration respectively) were recorded for each running trial. One way repeated measure ANOVA (condition by subject) were

performed on the subject means to compare each dependent variable (SA, impact peak (IP), active peak (AP), loading rate (LR)) between three stride length conditions (PSL, -15%PSL, +15%PSL). Results indicated that SA (PSL: $84 \pm 4.2\%$, +15%PSL: $87 \pm 6.4\%$, -15%PSL: $83 \pm 6.3\%$) in the time domain ($p = 0.053$) and in the frequency domain (PSL: $-38 \pm 9.3\text{dB}$, +15%PSL: $-39 \pm 9.9\text{dB}$, -15%PSL: $-40 \pm 10.8\text{ dB}$) ($p = 0.655$) were not significantly different among conditions. The mean values for SA in the time domain across conditions indicated a trend that SA increased with increasing SL. IP (PSL: $16 \pm 3.1\text{ N/Kg}$, +15%PSL: $16 \pm 2.9\text{ N/Kg}$, -15%PSL: $15 \pm 2.0\text{ N/Kg}$) ($p = 0.16$) and LR (PSL: $736 \pm 152.4\text{ N/Kg}$, +15%PSL: $681 \pm 191.9\text{ N/Kg}$, -15%PSL: $593 \pm 136.8\text{ N/Kg}$) ($p = 0.065$) were not significantly different across the SL conditions. Planned comparison results for LR indicated that -15%PSL was different ($p = 0.025$) from +15%PSL. No differences were observed between PSL and +15%PSL ($p = 0.413$) and -15%PSL and PSL ($p = 0.124$). However, a trend for LR was observed, that it increased with increasing SL. AP (PSL: $24 \pm 2.8\text{ N/Kg}$, +15%PSL: $23 \pm 3.7\text{ N/Kg}$, -15%PSL: $23 \pm 2.6\text{ N/Kg}$) was significantly different ($p = 0.045$) between conditions. Planned comparisons identified that PSL was significantly different ($p = 0.024$) from +15%PSL and from -15%PSL ($p = 0.016$). No difference was observed between -15%PSL and +15%PSL ($p = 0.813$). Mean values of the three conditions suggest that AP decreased with changes in SL. The SA, IP, AP and LR have been shown to increase with increasing SL in adults (Derrick et al. 1998). These findings suggest that children may manage impact and shock differently than adults. It is possible that our results may have been influenced by intra-subject variability, which was high among these child runners. Future investigations on child runner performance, focusing on variability as well as comparative adult patterns, are warranted.

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CHAPTER I

INTRODUCTION

Running is the exercise of choice for millions of people all over the world and across the age of spectrum. A main reason for its popularity stems from its simplicity. Pratt (1989) reported that the rapid rise in interest in running by a large number of people has produced much pleasure and many benefits but running has also been responsible for a large number of orthopedic problems. With the growth of youth sports programs, overuse injuries in young people have become common (DiFiori, 1999). For example apophyseal injuries such as tibial tubercle apophysitis (Osgood-Schlatter disease) and calcaneal apophysitis (Sever's disease), are common overuse injuries in adolescents (DiFiori, 1999).

Over the past 20 years there has been a phenomenal increase in sports participation by children (Koester, 2002). It has been estimated that 50% of all boys and 25% of all girls aged 8 to 16 in the United States participate in some form of organized, competitive sports (DiFiori, 1999). Marsh & Daigneault (1999) estimated this number to be 45 million each year. With the increase in number of children participants there will likely be a concomitant increase in the number of sports related injuries (Koester, 2002). Koester (2002), reported that it has been estimated that approximately 3 million injuries occur annually during sports participation among children and adolescents. He further reported that young girls playing organized sports have an estimated injury rate of 20-22

injuries per 100 participants per season and boys are almost twice as likely to be injured with a calculated rate of 39 injuries per 100 participants per season (Koester, 2002). Of the total number of injuries diagnosed in a sports medicine clinic, 50% of them were classified as overuse injuries (Watkins & Peabody, 1996) and running is considered as one of the activities causing overuse injuries (Rice, Waniewski, & Maharam, 2003).

During a typical 30 minute run by an adult, there are about 2500 collisions between runner's foot and the ground. With each foot strike during running, a shock wave is transmitted throughout the body, ultimately reaching the head (Mercer, Vance, Hreljac, & Hamill, 2002). One of the important functions of the human musculoskeletal system is to attenuate and dissipate shock waves initiated with foot ground contact (Verbitsky, Mizrahi, Voloshin, Treiger, & Isakov, 1998). Shock attenuation is the process of absorbing impact energy and reducing the amplitude of the shock wave (Derrick, Hamill, & Caldwell, 1998; Nigg, Cole, & Bruggemann, 1995). Adults absorb approximately 80% of the impact during running and are generally able to avoid injury (Mercer, Vance, Hreljac, & Hamill, 2002; Mercer, Bates, Dufek, & Hreljac, 2003). The amount of shock absorbed by pre adolescent runners has not been reported in the scientific literature. Gerritsen et al. (1995) hypothesized that overuse injuries in adult runners is related to the repetitive loading that occurs during running. It is possible that the same mechanism occurs in children leading to overuse injuries. However, there is very little information regarding impact characteristics or shock attenuation during running for children runners. This information is important since development of appropriate footwear is partially based upon modulating impact characteristics.

Purpose of the Study

The purpose of this study was to quantify shock attenuation and impact characteristics for children (boys and girls) running with different stride lengths.

Research Hypothesis

The Research hypothesis of this study is:

1. Shock attenuation will change with different stride lengths for children.
2. Impact Peak will change with different stride lengths for children.
3. Active Peak will change with different stride lengths for children.
4. Loading rate will change with different stride lengths for children.

Null and alternate hypotheses for the study will be:

$$H_{0SA} \mu_{PSL} = \mu_{-15\%PSL} = \mu_{+15\%PSL}$$

H_{0SA} : At Least Two Means will be Different

$$H_{0IP} \mu_{PSL} = \mu_{-15\%PSL} = \mu_{+15\%PSL}$$

H_{0IP} : At Least Two Means will be Different

$$H_{0AP} \mu_{PSL} = \mu_{-15\%PSL} = \mu_{+15\%PSL}$$

H_{0AP} : At Least Two Means will be Different

$$H_{0LR} \mu_{PSL} = \mu_{-15\%PSL} = \mu_{+15\%PSL}$$

H_{0LR} : At Least Two Means will be Different

1. Independent variable: Stride length
2. Dependent variables: Shock attenuation, Impact peak, Active peak and Loading rate

Definitions

1. Acceleration: The rate of change in velocity.
2. Peak impact acceleration of leg (a_{leg}): Peak acceleration of the leg recorded by an accelerometer mounted on the medial aspect of the distal tibia immediately after heel strike.
3. Peak impact acceleration of Head (a_{head}): Peak acceleration of the head recorded by an accelerometer mounted on the forehead immediately after heel strike.
4. Overuse running injuries: Injuries occurring when the musculoskeletal system receives repetitive stress over a period of time, causing fatigue effects beyond the capabilities of a specific structure (Elliott, 1990).
5. Shock Attenuation (SA): Shock attenuation (SA) is the process by which the impact shock caused by the collision between the foot and ground is reduced. Mathematically it is the measure of the reduction of the peak impact acceleration between the leg and head segments. The formula in the time domain is :
$$\text{Shock Attenuation (\%)} = 100 * (1 - a_{head} / a_{leg})$$
6. Shock wave: A wave initiated by the foot-ground contact that travels through the musculoskeletal system up to head. It is typically seen in the head profile approximately 10ms after it is seen in the leg profile (Derrick, Hamill, & Caldwell, 1998).
7. Fast Fourier Transformation (FFT): A class of algorithms used in digital signal processing that break down complex signals into elementary components. It is a faster way to determine the fourier coefficients of a function. Using this method a problem is divided into two problems of same type and process each of its sub-

problems. The gain is important since at each step the data to be processed will be divided by two.

8. Power spectral density (PSD): The spectral distribution of the power density as a function of frequency is called as power spectral density. The units of power spectral density are commonly expressed in watts per hertz (W/Hz). PSD gives power per unit frequency interval, i.e. the power density. Integrating this power density function yields the total power of the signal.
9. Stance Phase: The time period from the initial ground contact to toe-off.
10. Stride: One complete gait cycle starting at heel contact of the foot and ends at the heel contact of the same foot
11. Stride frequency: The number of strides taken in a given amount of time.
12. Stride length: The distance covered by one stride.

CHAPTER II

REVIEW OF LITERATURE

The vertical ground reaction force profile during running for heel toe runners is characterized by an early impact peak (Derrick, Caldwell, & Hamill, 2000). This is followed by a second peak referred to as the active peak (Derrick, Caldwell, & Hamill, 2000). The impact peak is generally observed within 20ms to 50ms of contact with the ground and reaches two to three times body weight (Bobbert, Yeadon, & Nigg, 1992; Cavanagh & LaFortune, 1980). The active peak takes place over the latter part of the stance period and occurs at approximately 200 ms (Hreljac, 2004).

Figure 1

Figure 1: Illustration of a typical vertical ground reaction force profile during running

The impact peaks that occur when the foot collides with the ground may have a causative role in running injuries (Hreljac, Marshall, & Hume, 2000). Although it is the impact peak that has most often been implicated in overuse running injuries, evidence exists (Messier & Pittala, 1988) which suggests that the active peak also plays a significant role in a variety of overuse injuries. Both of these peaks are also considered as one of the primary etiological agents in degenerative joint diseases and overuse injuries to the musculoskeletal system (Chi & Schmitt, 2005; Gerlach, White, Burton, Dorn, Leddy, & Horvath, 2005; James, Bates, & Osternig, 1978; Milner, Ferber, Pollard, Hamill, & Davis, 2006).

Overuse injuries of the musculoskeletal system generally occur when a structure is exposed to a large number of repetitive forces, each below the acute injury threshold of the structure, producing a combined fatigue effect over a period of time beyond the capabilities of the specific structures (Elliott, 1990; Stanish, 1984). Injuries such as stress fractures, medial tibial stress (shin splints), chondromalacia patellae, plantar fasciitis and Achilles tendinitis could all be classified as overuse injuries (Hreljac, Marshall, & Hume, 2000). Hreljac et al. (2000) divided the factors attributed to causing running injuries into three general categories: training, anatomical and biomechanical variables.

Training Factors Related to Overuse Injuries

Training variables that have been identified as contributing factors to running injuries are excessive running distance or intensity of the training program, rapid increases in weekly running distance or intensity (Hreljac, Marshall & Hume, 2000). The distance run per week has consistently been associated with running injuries. Some

authors (Jacobs & Berson, 1986; Macera, Pate, Powell, Jackson, Kendrick, & Craven, 1989; Marti, Vader, Minder, & Abelin, 1988) have reported that risk of injury is directly related to distance run per week. In long distance runners, increased training intensity is associated with increased distance. A significant relationship was found by Lysholm & Wiklander (1987) between injury rate during a given month and the distance covered during the preceding month. It was explained as a delay between an increased distance and the onset of symptoms which lead to hampering training (Lysholm & Wiklander, 1987).

Changes in surface, equipment, ignorance of earlier injury, inexperience in running or poor running technique can also play a role in causing overuse running injuries (Clement, Taunton, Smart, & McNicol, 1981; Harvey Jr., 1983; Johnson, 1983). Terrain is another important consideration for runners. The optimum running surface should deform sufficiently to help cushion impact yet be firm enough to supply ample stability (Stanish, 1984). Injury can occur when the habitual surface is suddenly changed with changes in training volume. Improper skill technique is another important risk factor (Stanish, 1984). Inexperienced runners sustain more injuries than experienced runners because excessive training exceeds functional adaptive structural response of the body as well as poor running technique (Clement, Taunton, Smart, & McNicol, 1981; Glick & Katch, 1970). Running uphill or downhill has been reported to produce overuse injuries (Clement, Taunton, Smart, & McNicol, 1981; James, Bates, & Osternig, 1978). Some authors (Blair, 1985; McKenzie, Clement, & Taunton, 1985) reported no difference in incidence of injury for running on different surfaces as well as increase in weekly mileage during training. The reason for this contradiction may be training errors cannot

be the only cause for overuse injuries; anatomical and biomechanical factors also play an equal role in etiology of injuries.

Anatomical Factors Related to Overuse Injuries

A large number of anatomical factors have been implicated as possible causes of overuse injuries. Number of authors (Cowan, Jones, & Robinson, 1989; Dahle, Mueller, Delitto, & Diamond, 1991; McKenzie, Clement, & Taunton, 1985; Messier & Pittala, 1988; Simkin, Leichter, Giladi, Stein, & Milgrom, 1989; Warren & Jones, 1987; Williams III, McClay, & Hamill, 2001) have reported that runners with high longitudinal arches are at an increased risk of injury during running. Some authors also observed low arch to be a factor causing overuse running injuries (Dahle, Mueller, Delitto, & Diamond, 1991; McKenzie, Clement, & Taunton, 1985; Simkin, Leichter, Giladi, Stein, & Milgrom, 1989; Warren & Jones, 1987; Williams III, McClay, & Hamill, 2001).

Williams et al. (2001) reported high arch runners suffered from more lateral injuries such as stress fracture of the fifth metatarsal, lateral ankle sprains, ilio-tibial band friction syndrome, while low arch runners suffered more injuries to the medially placed structures such as posterior tibial tendonitis, stress fracture of the second and third metatarsals, patellar tendonitis and medial knee pain. The mechanism behind these injuries is that runners with a cavus foot have decreased motion at subtalar joint as well as decreased internal rotation of tibia. This lack of movement results in decreased ability of the foot to absorb force during ground contact (McKenzie, Clement, & Taunton, 1985; Williams III, McClay, & Hamill, 2001). In the case of low arch runners, excessive pronation of the foot places increased stress on the medial structures of the lower

extremity (Messier & Pittala, 1988; Warren & Jones, 1987; Williams III, McClay, & Hamill, 2001). However others researchers (Montgomery, Nelson, Norton, & Deuster, 1989; Rudzki, 1997; Wen, Puffer, & Schmalzried, 1997) did not find arch height to be a risk factor in running injuries. A cavus foot was present in 20% of injured runners in the study of James, Bates, & Osternig, (1978). However, no such deformity was found by Rolf (1995) in his study between injured and uninjured runners.

Anatomical factor such as range of motion in plantar and dorsi flexion has also been related to running injuries. James et al. (1990) reported that runners with greater range of motion in plantar flexion have more injuries than runners with less mobility in the same. Warren & Jones (1987) explained that increased plantar flexion allows the runner more time to impart a backward or propulsive force, thereby creating more stress on the plantar structures of the foot. Van Mechelen et al. (1993) reported no difference in ankle range of motion between a group of runners with lower extremity injuries and a group of controls.

Tibia varum, rearfoot varus and leg length discrepancies have also been considered as the factors associated with overuse running injuries (James, Bates, & Osternig, 1978; Stanish, 1984) while others did not find lower extremity alignment abnormalities to be associated with an increased risk of overuse injuries in runners (Wen, Puffer, & Schmalzried, 1997). During running the lower extremities experience compressive loading. A tibia in varus will likely experience greater bending moments as the vertical force projects medial to the tibial shaft. This can result in greater susceptibility to tibial stress fracture (Milner, Ferber, Pollard, Hamill, & Davis, 2006). Milner et al. (2006) reported that bone structure can also contribute to the overall risk of

tibial stress fractures. In the tibial stress fracture group they observed that the tibial area moment of inertia was small. Milgrom et al. (1989) also reported the same results in case of male military recruits.

Some authors (Clement & Taunton, 1980; Hreljac, Marshall, & Hume, 2000) supported the speculation that lack of flexibility could also lead to overuse injuries in runners. Lack of flexibility may increase the stiffness of a muscle, putting more stress on the adjacent joints. Poor flexibility can also cause muscular imbalance which would lead to improper mechanics during running (Hreljac, Marshall, & Hume, 2000).

Biomechanical Factors Related to Overuse Injuries

Hreljac et al. (2000) reported that the majority of biomechanical factors that have been linked to overuse running injuries could be classified as either kinetic variables or rearfoot kinematic variables. Kinetic variables which are considered to be the cause of overuse running injuries are the magnitude of impact forces (Clement & Taunton, 1980), the impact loading rate (Nigg, 1986), and the magnitude of the push off forces (Winter, 1983). Hreljac et al. (2000) reported that runners with at least one previous overuse injury had a significantly greater magnitude and rate of impact loading than runners who were injury free. However, in a study of non injured runners and runners with anterior knee pain it was reported that non injured runners had greater peak forces and loading rates than the injured runners (Duffey, Martin, Cannon, Craven, & Messier, 2000). Crossley et al. (1999) observed no difference in GRF in male runners with and without a history of tibial stress fracture.

The rearfoot kinematic variables that have most often been associated with overuse running injuries are the magnitude and rate of foot pronation (Hreljac, Marshall, & Hume, 2000). Pronation during stance is necessary to dissipate impact forces but, it must end before midstance to allow the foot to become more rigid during push off (Subotnick, 1985). Hreljac et al. (2000) reported that an injury free group pronated rapidly whereas an injured group over pronated. Several studies have suggested that excessive pronation is a contributing factor to overuse running injuries (Clement & Taunton, 1980; James, Bates, & Osternig, 1978; James, Bates, & Osternig, 1990; Rolf, 1995). James et al. (1978) reported that excessive or prolonged pronation during the support phase is associated with increased stresses being applied to the supporting structures of the foot. In a normal gait cycle pronation and supination of the subtalar joint is associated with an obligatory tibial rotation. James et al. (1978) reported that the tibia rotates internally with foot pronation and rotates externally with supination of the foot. During this time of the gait there is a simultaneous transverse plane rotation occurs at the knee joint. During excessive pronation internal tibial rotation is increased and prolonged simultaneously the transverse rotation at the knee joint is also prolonged. Due to this, the normal tibial-femoral relationship at the knee joint is likely to be perturbed and may well account for much of the high incidence of knee problems in runners (James, Bates, & Osternig, 1978).

Ekenman et al. (1998) reported that the tibia is also exposed to combination of bending, shearing and torsion simultaneously during activities such as running. Milner et al. (in Press) reported that peak adduction free moment, free moment at peak braking force, and absolute peak free moment were significantly higher in runners with a history

of tibial stress fracture compared to runners with no previous lower extremity bony injury. With these results they reported that the magnitude of absolute peak free moment predicted a history of stress fracture in 66% of cases among the group studied (Milner, Davis & Hamill, Article in Press). The free moment is the torque about a vertical axis due to friction between the foot and the ground during stance. Free moment has been linked to pronation although it is not a direct measure of the torque acting on the tibia. However, higher free moment is likely to contribute to higher torque at tibia (Milner, Davis & Hamill, in Press).

Overuse Injuries in Children

There is whole new genre of injuries occurring in children engaged in organized sports. These are overuse injuries such as lower extremity tendonitis and apophysitis (Micheli, 1983). The incidence of such injuries seems to be related to the total distance covered in training and competition (Micheli, Santopietro, Gerbino, & Crowe, 1980). A child with shorter stride length subjects himself to more repetition of impact to cover the same distance as an adult (Rice, Waniewski, & Maharam, 2003). From two longitudinal studies done by Rauh et al. (2000) and Rauh et al. (2006) on high school athletes in Seattle over a fifteen year period, the activity with the highest rate of injuries was girls cross country. This injury rate was significantly higher than the other known high risk sports. A high rate of injury was also reported in boys cross country runner. Thus, distance running among adolescent boys and girls is associated with high injury rates (Rauh, Margherita, Rice, Koepsell, & Rivara, 2000; Rauh, Koepsell, Rivara, Margherita, & Rice, 2006).

The most common musculoskeletal problems in the young runners are a result of overuse. These include epiphyseal plate injuries, stress fracture and patellofemoral syndrome (Caine & Lindner, 1984; Micheli, Santopietro, Gerbino, & Crowe, 1980). Such overuse injuries may lead to chronic disability (Nelson, Goldberg, Harris, Landry, & William, 1990). It is well known that stress fractures, a distinct overuse injury, are a function of the number of repetitions and amount of applied force per repetition (Milner, Ferber, Pollard, Hamill, & Davis, 2006). Coady et al. (1997) reported that prior to the advent of organized sports for children, stress fractures in this age group were rare. However, with repetitive training for sports now being initiated as early as age 6, these injuries have become more common. The relative incidence of stress fracture appears to increase with age (Coady & Micheli, 1997). It was reported that 9% of the stress fractures occurred in children less than 15 year old, 32% in the 16-19 year olds and 59% in patients older than 20 years old (Orava, Jormakka, & Hulkko, 1981). The bones of the children and adolescents differ from those of adults with respect to the strength, elasticity and remodeling potential. The lower extremity is the most common site of stress fractures in children as well as adults (Coady & Micheli, 1997). Coady et al. (1997) further reported that the most common location of stress fracture in children and adults is the tibia. In pre-pubescent, the upper third of the tibia is usually affected (Engh, Robinson, & Milgram, 1970; Walter & Wolf, 1977). The peak incidence of stress fractures of the tibia in children is in the range of 10-15 years, but they have been described in children as young as 6 years (Donati, Echo, & Powell, 1990). Fibular stress fractures are usually located in the distal two thirds. Foot and ankle stress fracture are commonly seen in dancers and distance runners, most often involving the metatarsals (Coady & Micheli, 1997). Coady

et al. (1997) also mentioned that sesamoid stress fractures are another source of overuse onset pain in the foot. These are usually seen in runners and ballet dancers. Young athletes involved in sports with extended running and jumping may present with midfoot or medial arch pain, which worsens with prolonged activity and persists into post-exercise rest, can lead to navicular stress fracture causing avascular necrosis of the central third of the navicular bone (Vanderhave & Miller, 2005).

Effect of Injuries on Growth

Children may have less resilient and weaker muscle tendon units compared to adults that may be susceptible to injuries, when confronted with intense physical challenges that apply repetitive stress to tissues, which leads to injuries (Micheli & Fehlandt Jr., 1992). Micheli et al. (1983) reported that growth and development and the growth spurt in particular, are unique risk factors for injury in the athletic child and adolescent. There is clinical and biomechanical evidence that the growth cartilage is less resistant to repetitive micro trauma than is adult cartilage (Micheli, 1983).

Micheli et al. (1983) and Gerrard et al. (1993) described three distinct sites of growth cartilage in the child. First the epiphyseal plate which is located at the ends of long bones. The so called epiphyseal plate closure signals fusion of primary and secondary center of ossification and is called bone maturation. Second, is the joint surface and third is the apophyseal insertion of the muscle tendon unit attached to bone. These three sites are vulnerable to repetitive forces and often implicated in pre-adolescent overuse injury (Gerrard, 1993). According to Nanni et al. (2005) the weakest biomechanical portion of the growing skeleton is the physeal region. Poor athletic

technique and mechanisms that increase loads across the epiphysis make the skeletally immature athlete prone to injury. Physeal stress fracture causes widening of the physis and fragmentation of metaphyses. These symptoms arose primarily from running related activities, including long distance running (Caine, DiFiori, & Maffulli, 2006). It can also occur when repetitive loading produces metaphyseal ischaemia, which results in the inhibition of mineralization in the zone of provisional calcification (DiFiori, 2002). Chondrocytes continue to proliferate and cause growth plate widening and can lead to partial or complete growth arrest (DiFiori, 2002).

At the joint, immature articular cartilage is more susceptible to shear force than adult cartilage and predisposed children to osteochondritis dissecans (Koester, 2002; Rice, Waniowski, & Maharam, 2003). Ankle, knee and elbow are the most commonly affected joints by osteochondritis dissecans (DiFiori, 2002). During the growth spurt, adolescents are particularly vulnerable to injuries (DiFiori, 2002; Helms, 1997). During this time, rapid changes in the length, mass and moment of inertia of the extremities results in increased stress on muscle tendon junctions, bone tendon junctions (apophyses), ligaments and growth cartilage (DiFiori, 2002; Hawkins & Metheny, 2001). The traction apophyses can also be the site of overuse injury (Micheli, 1983). Apophysitis describes the process of tiny avulsion fractures to the physeal plate with subsequent secondary inflammatory changes (Micheli & Fehlandt Jr., 1992). Overuse apophyseal conditions such as Osgood-Schlatter disease, Sever's disease, patellar tendonitis, Achilles tendinitis, patello-femoral stress syndrome and calcaneal apophysitis is frequently seen in the young athlete (Adirim & Cheng, 2003; Caine, 2006; DiFiori, 1999; DiFiori, 2002; Gerrard, 1993; Koester, 2002; Micheli, 1983; Micheli & Fehlandt

Jr., 1992; Rice, Waniowski, & Maharam, 2003). Apophyseal injury occurs as a consequence of stress at immature tendon-bone attachment sites (DiFiori, 2002). Muscle lengths in response to bone growth, therefore there is a susceptible period when the muscle is shorter than the length of the bone. The result is constant tension on the apophysis, which is exacerbated by repetitive activity (Koester, 2002). This discrepancy may also increase stress on the apophyses and at the joint surface (DiFiori, 1999). With repeated stress placed on the apophysis, there might be some weakening in the growth cartilage matrix, culminating in inflammation, pain and loss of function (Koester, 2002). The weakness of the growth cartilage relative to the tendon is a contributing factor in these apophyseal injuries. Decreased flexibility, also causes increased stress at the apophyseal insertion of the tendon has also been considered one of the factors leading to apophyseal injuries (DiFiori, 2002; Hawkins & Metheny, 2001; Koester, 2002; Micheli, 1983; Micheli & Fehlandt Jr., 1992; Rice, Waniowski, & Maharam, 2003). The collagen fibers and growth cartilage of the apophyses are the weak link in the muscle tendon unit and are subjected to injury from repetitive load (Micheli, 1987). Hawkins et al. (2001) describes the effect of growth on the strength of tendon, apophysis, ligament and bone. A muscle group may adapt quickly to accommodate increased demands created either by changes in limb inertial properties or changes in physical activity and generate greater force by increasing its size (Hawkins & Metheny, 2001). They further explain that if the tendon and apophysis associated with that muscle group adapt slowly then the stress induced in the tendons and apophyses will increase in response to the increased muscle force and perhaps lead to injury.

Factors Effecting Shock Attenuation

Impact force magnitudes are influenced by running velocity such that force magnitudes increase with faster velocities (Hamill, Bates, Knutzen, & Sawhill, 1983; Mercer, Vance, Hreljac, & Hamill, 2002; Munro, Miller, & Fuglevand, 1987). Impact force magnitude is also influenced by changes in the stride length (Derrick, Caldwell, & Hamill, 2000) such that force magnitude increases with longer stride lengths. During running, this impact force is attenuated through joint actions as well as anatomical structures (Derrick, Hamill, & Caldwell, 1998; Hamill, Derrick, & Holt, 1995; Mercer; Devita, Derrick, & Bates, 2003). The process of reducing the impact magnitude between the head and the leg has been termed shock attenuation (Mercer, Vance, Hreljac, & Hamill, 2002). Understanding factors that affect shock attenuation is important because the magnitude and the rate of the large impact forces during the stance phase of running are considered to be related to overuse injuries (James, Bates, & Osternig, 1978; Nigg, Cole, & Bruggemann, 1995).

Shock attenuation may be affected by lower extremity geometry at impact because the magnitude of impact is affected by the spatial orientation of the lower extremity segments at the moment of impact (Derrick, Hamill, & Caldwell, 1998; Derrick, Caldwell, & Hamill, 2000; Lafortune, Hennig, & Lake, 1996; Lafortune, Lake, & Hennig, 1996; McMahon, Valiant, & Frederick, 1987). The lower extremity stiffness varies with geometry and changes in stiffness can alter impact magnitude (Derrick, Caldwell, & Hamill, 2000). For example, running with a greater knee flexion angle at impact can reduce lower extremity stiffness and increase shock attenuation (McMahon, Valiant, & Frederick, 1987).

It has been observed that shock attenuation increased as running velocity increased (Mercer, Vance, Hreljac, & Hamill, 2002; Mercer, Bezodis, Russell, Purdy, & DeLion, 2005; Winslow & Shorten, 1989). Mercer et al. (2002) reported 60% increase in shock attenuation across 50-100% speed conditions resulting in a 20% increase per 1 m/s increase in speed. This result is similar to the Winslow & Shorten (1989) study, who observed a 15% increase in shock attenuation for 1 m/s increase in speed. The role of running velocity on shock attenuation is dependent on stride length (Mercer, Bezodis, Russell, Purdy, & DeLion, 2005). Interestingly when stride length was constrained across the different running speeds the change in shock attenuation was less compared to running at preferred stride length (Mercer, Bezodis, Russell, Purdy, & DeLion, 2005). It has also been observed that shock attenuation increased with increase in stride length keeping the velocity either constant (Derrick, Hamill, & Caldwell, 1998; Mercer, Devita, Derrick, & Bates, 2003) or variable (Mercer, Vance, Hreljac, & Hamill, 2002). So it can be concluded from the above studies that there is a strong relationship between shock attenuation and stride length.

Fatigue is also considered as one of the factors that affects shock attenuation (Verbitsky, Mizrahi, Voloshin, Treiger, & Isakov, 1998). It is often defined as a reduction in the force generating capacity of the neuro-muscular system (Nummela, Stray-Gundersen, & Rusko, 1996). It is also defined as the 'failure to maintain the required or expected force or power output' (Maclaren, Gibson, Parry-Billings, & Edwards, 1989). Fatigue affects both stride length and stride rate, although it was observed that the decrease in stride length was greater (Bates & Haven, 1974). Decrease in stride length causes decrease in shock attenuation (Mercer, Devita, Derrick, & Bates, 2003). It has

been hypothesized that bone overuse injuries are related to fatigued muscle because of the loss of shock absorbing capacity of the muscle (Mercer, Devita, Derrick, & Bates, 2003). It was observed by Verbitsky (1998), that the acceleration amplitude steadily increased in the tibial tuberosity with running time in the fatigue group. Mercer, Vance, Hreljac, & Hamill (2002) also observed that fatigue increases peak impact acceleration of the leg which shows reduction in shock attenuation. However, Derrick et al. (2002) reported that with the increase in peak impact acceleration there was a significant increase in shock attenuation from the start to the end of an exhaustive run. According to Derrick et al. (2002) this increase in impact acceleration was not considered an injury risk. He explained that there is a role of effective mass and angles of the joints of the lower extremity in determining shock attenuation properties.

Ground reaction forces are certainly related to leg acceleration as per Newton's second law, but the relationship between force and acceleration is modified by the effective mass. The entire body is not accelerated during the impact and the effective mass constitutes the portion of the mass accelerated by a force (Denoth, 1986; Valiant, 1990). The effective mass is the portion of the total system that needs to be known in order to accurately model the impact (Derrick, 2004). Simple spring mass models have been successfully used to simulate human running (Farley & González, 1996; Kim, Voloshin, & Johnson, 1994). However these models assumed only rigid body segments in their simulations. The human body corresponds to a mechanical system of rigid and non rigid masses, which are attached to each other through elastic and viscous connections (Liu & Nigg, 2000). These shall also be taken into consideration while making a model to study impact forces. Denoth (1986) observed the relationship between

initial knee angle and the effective mass for various activities. In fact changes in the knee contact angle appear to have greatest influence on effective mass at about 160- 170 deg. Denoth (1986) demonstrated the dependency of effective mass on knee angle using a combination of modeling results and experimental data for activities such as walking, running, and jumping. For a single barefoot subject with a body mass of 65 kg, the results indicated that increasing knee flexion from 5° to 20° would decrease effective mass of the body from 11 to 5 kg. The relationship between knee flexion and effective mass appears to be relatively linear (Denoth J., 1986). Denoth (1986) reported that during ground contact the more the knee is in extended position the more will be the effective mass. Because a smaller effective mass is easier to accelerate, peak accelerations would be expected to increase as the knee becomes flexed at contact. It was reported that decreasing the effective mass will increase the peak accelerations while at the same time decrease the impact forces (Derrick, 2004). For example, Liu et al. (2000) reported in his muscle model that an increase in the lower rigid mass as well as lower wobbling mass produced incremental increases in the impact force peak. A simulation study by Gerritsen et al. (1995) estimated that a more flexed knee position at contact would decrease the peak impact force by approximately 68 N per degree of flexion. Another study reported that with the decrease in effective mass the impact forces decreased among different gaits (Chi & Schmitt, 2005). It was concluded that a decrease in effective mass of the limb leads to a decrease in impact magnitude during running (Denoth, 1986). Effective mass can be decreased by increasing knee contact angle (Derrick, 2004; McMahon, Valiant, & Frederick, 1987). Change in stride length causes a change in knee contact angle (McMahon, Valiant, & Frederick, 1987; Mercer, Bezodis, Russell, Purdy, & DeLion,

2005). Therefore, stride length becomes an important factor, which can be manipulated to reduce impact force magnitude.

Schepens et al. (1998) observed that stride length was different for children of different age groups for a given running speed. He found that younger children ran with shorter stride lengths than older children, probably due to decreased lower extremity stiffness for young runners. Lower extremity stiffness can be decreased by increasing the amount of knee flexion during the stance phase of running. Schepens et al. (1998) reported that children's morphology was a critical factor determining running mechanics. Children are not small adults because of their anatomy and physiology (Rolf, 1995). It has been described earlier how shock attenuation as a parameter can be used to measure impact forces which if reduced, can prevent overuse running injuries in adults. Similarly knowledge of shock attenuation will definitely be helpful parameter in understanding these injuries in children too. If the relationship between shock attenuation and stride length will hold true in the case of child runners, shock attenuation may be used as a variable that could be further investigated and become a technique to prevent overuse running injuries in children.

Summary of Literature Review

Running is an activity that results in repetitive foot collisions with the ground, which can lead to high risk of overuse running injuries. Overuse injuries of the musculoskeletal system generally occur when a structure is exposed to a large number of repetitive forces, each below the acute injury threshold of the structure, producing a combined fatigue effect over a period of time. This combined fatigue can be beyond the

capabilities of the specific structures to maintain healthy status and results in tissue damage and injury (Elliott, 1990; Stanish, 1984).

Hreljac et al. (2000) divided the factors attributed to causing running injuries into three general categories: training, anatomical and biomechanical variables. The most common factors contributing to overuse injuries among training variables are considered to be running distance per week (Jacobs & Berson, 1986; Macera, Pate, Powell, Jackson, Kendrick, & Craven, 1989), rapid change in the intensity of the program (Lysholm & Wiklander, 1987) and change in running surface (Stanish, 1984). Anatomical factors contributing to running injuries include high and low arches of the foot (Warren & Jones, 1987; Williams III, McClay, & Hamill, 2001), greater range of motion in planter flexion (James, Bates, & Osternig, 1978), tibial varus and tibial area of moment of inertia (Milner, Ferber, Pollard, Hamill, & Davis, 2006) are the cause of biomechanical dysfunction leading to overuse running injuries. Biomechanical factors causing overuse running injuries can be divided into kinetic and kinematic variables. Clement and Taunton, 1980 and Nigg 1986 reported that greater the magnitude of impact force lead to the greater chances of getting injured (Clement & Taunton, 1980; Nigg, 1986). Excessive foot pronation (Hreljac, Marshall, & Hume, 2000) and increased internal rotation of tibia (James, Bates, & Osternig, 1978) during stance phase of running can result in various knee injuries.

Over the past 20 years there has been a phenomenal increase in sports participation by children (Koester, 2002). Of total number of injuries diagnosed in a sports medicine clinic, 50% of them were overuse injuries (Watkins & Peabody, 1996) and running is considered as one of the primary activities for many of the reported

overuse injuries (Rice, Waniewski, & Maharam, 2003). The bones of the children and adolescents differ from those of adults with respect to the strength, elasticity and remodeling potential. The lower extremity is the most common site of stress fractures in children as well as adults (Coady & Micheli, 1997). It was reported that 9% of the stress fractures occurred in children less than 15 year old, 32% in the 16-19 year olds and 59% in patients older than 20 years old (Orava, Jormakka, & Hulkko, 1981). Micheli, (1983) reported that growth and development, and the growth spurt in particular, are unique risk factors for injury in the athletic child and adolescent. According to Nanni et al. (2005) the weakest biomechanical portion of the growing skeleton is the physeal region. Repetitive loading produces metaphyseal ischaemia, which results in the inhibition of mineralization in the zone of provisional calcification. Chondrocytes continue to proliferate and cause growth plate widening and can lead to partial or complete growth arrest (DiFiori, 2002).

The shock wave generated during the foot-ground contact is attenuated not only externally but also internally through the musculoskeletal structure of a runner. Shock attenuation is the process of absorbing impact energy and reducing the amplitude of the shock wave (Derrick, Hamill, & Caldwell, 1998; Nigg, 1995). Shock attenuation may be affected by lower extremity geometry at impact because the magnitude of impact is affected by the spatial orientation of the lower extremity segments at the moment of impact (Derrick, Hamill, & Caldwell, 1998; Derrick, Caldwell, & Hamill, 2000; Lafortune, Lake, & Hennig, 1996; McMahon, Valiant, & Frederick, 1987). It has also been observed that shock attenuation increased with increase in stride length keeping the velocity either constant (Derrick, Hamill, & Caldwell, 1998; Mercer, Devita, Derrick, & Bates, 2003) or variable (Mercer, Vance, Hreljac, & Hamill, 2002). Therefore, it can be

discussed from the published research that there is a strong relationship between shock attenuation and stride length. This SA-SL relationship in children has not been reported in the scientific literature. If the reported adult relationship holds true in children, shock attenuation may be used as a variable that could be further investigated and become a technique to prevent overuse running injuries in children.

CHAPTER III

METHODS

Subjects

Ten physically active children (4 boys and 6 girls, 10.7 ± 1.1 yrs; 40 ± 10.3 kg; 145.2 ± 7.3 cm), free from any current injury or previous lower extremity injury, were recruited to be subjects in this study.

Instrumentation

Ground reaction forces were measured using a force platform (Kistler Instrument Corporation USA, Amherst, NY; Model #9281C) mounted flush with the floor in the middle of a 20m runway. Leg and head impact acceleration were quantified by securing two light weight uni-axial accelerometers (PCB Piezotronics, Depew, NY, model: 353C67, 6.7 grams, ± 50 -g range, frequency range = 0.5 Hz – 5 KHz) to the body. One accelerometer was secured to the anterior- medial region of the distal aspect of right tibia (Figure 2) (Valiant, McMahon & Frederick, 1987) just superior to the medial malleoli. The accelerometer was secured with elastic straps tightened to the threshold of subject tolerance. The second accelerometer was attached to a plastic head gear similar to a baseball hat that can be tightened about the head. The accelerometer is mounted on the front aspect of the head (i.e. forehead) (Figure 3) with the sensitive axes of both accelerometers aligned vertically. The sensitive axes of the two accelerometers may

change during manipulation of stride length. However, previous research reported (Derrick, Hamill, & Caldwell, 1998) that changes in the alignment of the leg accelerometer during stride length that were 40% different affected acceleration magnitude by only 0.1g (about 1-2% of impact peak magnitude). These sites were selected as they have minimal soft tissue oscillations during the impact. Accelerometer data were collected at 1008 Hz for all the trials. Running velocity was determined using two infrared photo sensors (Lafayette Instrument Corporation. USA, Lafayette, IN; model 635011R) that triggered the signal when the subject ran past a sensor. Sensors were placed 1.5 m before and after the force plate in order to determine running velocity. All data were collected at 1008 Hz using Bioware (Kistler Instrument Corporation, Depew, NY; version 3.21) data acquisition software.

Figure 2: Illustration of placement of leg accelerometer

Figure 3: Illustration of head accelerometer

Experimental Protocol

Upon entering the laboratory, all parents (or local guardians) of children gave written informed consent prior to completing any activity associated with the study. In

addition, parents/guardians were asked verbally about the past medical history of the child if he/she has been injured before or if there was anything that would prevent the child from running. This information was used to screen potential child runner. If parent reported any kind of present or past history which makes the child prone to injury, the child did not qualify to be a subject. The consent forms used were approved by the University of Nevada, Las Vegas's Biomedical Institutional Review Board. Following granting of consent, children subjects completed an orientation session where they ran with accelerometers in place. No child was tested if she or he was unable to comfortably run during the orientation session.

Figure 4: Illustration of the testing zone and marker placement to maintain target SL

An area approximately 20m in length was used for testing (Figure 4). Timing lights were placed across the testing zone to monitor running speed. Children were instructed verbally and by demonstration in how to maintain correct stride length. Preferred stride length (PSL) was defined as the freely chosen stride length at a running velocity of 3 m/s. This velocity was chosen because it has already been tested with children of this age successfully (Schepens, Willems, & Cavagna, 1998). Each subject ran in three stride length conditions: PSL, +15% of PSL, -15% of PSL. In all conditions the velocity was 3 m/s. Markers were placed on the runway to assist the subject in maintaining correct stride length (Figure 4). Subjects practiced each stride length condition until they felt comfortable meeting the condition of an acceptable trial. A minimum of ten acceptable trials per stride length condition were obtained from each subject. Trials were accepted if the velocity was within + or - 5% of 3 m/s, if there was no visible alteration of the stride length and if the right foot of the subject fell entirely on the force platform (Figure 5).

Figure 5: Illustration of foot on the force plate for an accepted trial

Upon completion of each run through the testing zone, running velocity was calculated and compared. If the speed was greater or lesser than + or – 5% of the target speed, appropriate instructions were given (run a little slower, speed up a bit), and the condition was repeated. Throughout the data collection session, water and non carbonated beverages were provided to the runners, as requested.

Data Reduction

Peak impact acceleration values from the leg and head acceleration were recorded immediately after heel strike for different stride lengths. Shock attenuation was quantified in 1) Time and 2) Frequency domain. The units of shock attenuation in the Frequency domain and Time domain are decibels and percentage respectively. For each subject stance phase head and leg acceleration profiles which coexist with the force plate data were extracted for all accepted trials per condition and transformed to the frequency domain. Figure 6 illustrates head (c) and leg (d) acceleration profiles with event markers identifying beginning and ending points of a data set extracted for analysis. This acceleration pattern was typical in all strides for all subjects and all conditions and has been observed using surface mounted accelerometers (Derrick, Hamill, & Caldwell, 1998; McMahon, Valiant, & Frederick, 1987; Winslow & Shorten, 1989). The beginning event was identified as the local minimum on the leg acceleration profile just before the distinct positive impact peak with the ending event as the local minimum after a low magnitude peak. These selection criteria allowed for analysis of similar patterns between strides and conditions. Within the extracted data set, the section of interest was the impact phase, which consisted of primarily a large positive peak followed by a negative peak.

(a)

(b)

(c)

(d)

Figure 6

Figure 6: Illustration of Timing lights (a), vGRF (b), Head (c) and leg (d) acceleration profiles (3sec) during running for single subject. The stance phase for leg and head acceleration profile co-exist with the vGRF profile. This stance phase was extracted for the frequency analysis.

To analyze in the frequency domain, mean and linear trends were first removed from each data set. The length of the data set needed to be a power of two in order to calculate power spectral density (PSD) using fast Fourier transformation function. Data sets were therefore padded with zeros in order to total 1024 data points per acceleration profile. Power spectral densities were calculated for padded data sets, with PSD adjusted to account for changes in power due to the zero padding procedure by accounting for the number of zeros added to the data set (Winslow & Shorten, 1989). Shock attenuation was calculated as the ratio of leg Power Spectral Density (PSD) across the 11-20Hz frequency range. Shock attenuation was calculated using the following formula:

$$\text{Shock Attenuation (dB)} = 10 \times \log_{10} (\text{PSD}_{\text{head}}/\text{PSD}_{\text{leg}})$$

Where PSD_{head} and PSD_{leg} represent the mean power spectral density across the 11-20Hz frequency range for the head and leg respectively. A low ratio between PSD_{head} and PSD_{leg} (i.e., high percent shock attenuation) indicated greater attenuation of the impact magnitude. Units for shock attenuation are decibels (dB), where positive values indicate gain and negative values attenuation of PSD_{leg} relative to PSD_{head} . In the time domain shock attenuation was calculated by using the formula:

$$\text{Shock Attenuation (\%)} = 100 \times (1 - a_{\text{head}}/a_{\text{leg}})$$

Where a_{head} represents the peak impact acceleration recorded from the head acceleration profile and a_{leg} represents the peak impact acceleration recorded from the leg acceleration

profile. These data points were extracted from the actual acceleration profiles. Ground reaction force data were collected from heel strike to toe off, analog to digitally converted at 1008Hz. Impact peak and active peak forces for various stride lengths were extracted from the vertical GRF curve. Loading rates were calculated as the gradient between 20% from heel strike to 80% before impact peak (Mullineaux, Milner, Davis, & Hamill, 2006). Force data were normalized to subject body mass.

Statistical Analysis

The dependent variables were shock attenuation, impact peak, active peak and loading rate. Stride length (PSL, +15% of PSL, -15% of PSL) was the independent variable. In addition to these dependent variables, the peak impact acceleration both at leg and head were compared between stride length conditions. Mean values were calculated across trials for each condition. One way repeated measures ANOVA (condition by subject) were performed on the subject means (Keppel G, 1982). Regardless of the F – ratio ($p < 0.05$ or $p > 0.05$), planned comparison tests (Least significant difference test or LSD) between PSL and -15%PSL, PSL and +15%PSL and -15%PSL and +15%PSL were performed. All statistical tests were conducted using SPSS (version 13.0) software, with $\alpha = 0.05$.

CHAPTER IV

RESULTS

Shock attenuation (SA) was not different ($p = 0.053$) between the stride length conditions (PSL: $84 \pm 4.2\%$, +15%PSL: $87 \pm 6.4\%$, -15%PSL: $83 \pm 6.3\%$) in the time domain analysis. Furthermore, shock attenuation was not different ($p = 0.655$) between stride length conditions (PSL: $-38 \pm 9.3\text{dB}$, +15%PSL: $-39 \pm 9.9\text{dB}$, -15%PSL: $-40 \pm 10.8\text{dB}$) in the frequency domain analysis.

Figure 7

Figure 7: Illustration of shock attenuation (SA) in time domain across the three strides length (SL) conditions. SA was not different ($p > 0.05$) between the stride length conditions.

Figure 8

Figure 8: Illustration of shock attenuation (SA) in frequency domain across the three strides length (SL) conditions. SA was not different ($p > 0.05$) between the stride length conditions.

Peak impact acceleration of the leg in time domain was not different ($p = 0.213$) between the stride length conditions (PSL: $6.8 \pm 3.1g$, +15%PSL: $8.2 \pm 2.9g$, -15%PSL: $6.1 \pm 3.7g$).

Figure 9

Figure 9: Illustration of peak impact acceleration of the leg (g = acceleration due to gravity) across the three stride length conditions. Leg peak was not different ($p > 0.05$) between the stride length conditions.

Peak impact acceleration of the head in time domain was not different ($p = 0.155$) between the stride length conditions (PSL: $1.1 \pm 0.5g$, +15%PSL: $1.0 \pm 0.5g$, -15%PSL: $1.0 \pm 0.4g$).

Figure 10

Figure 10: Illustration of peak impact acceleration of the head (g = acceleration due to gravity) across the three stride length conditions. Leg peak was not different ($p > 0.05$) between the stride length conditions.

Impact peak was not different ($p = 0.16$) between the stride length conditions (PSL: 16 ± 3.1 N/Kg, +15%PSL: 16 ± 2.9 N/Kg, -15%PSL: 15 ± 2.0 N/Kg).

Figure 11

Figure 11: Illustration of impact peak (IP) (N/Kg) across the three strides length (SL) conditions. Impact peak was not different ($p > 0.05$) between the stride length conditions.

Loading rate was not different ($p = 0.065$) between the stride length conditions (PSL: 736 ± 152.4 N/Kg/sec, +15%PSL: 681 ± 191.9 N/Kg/sec, -15%PSL: 593 ± 136.8 N/Kg/sec).

Figure 12

Figure 12: Illustration of loading rate (LR) (N/Kg/sec) across the three strides length (SL) conditions. Loading rate was not different ($p < 0.05$) between the stride length conditions.

Active peak was different ($p = 0.045$) between the stride length conditions (PSL: 24 ± 2.8 N/Kg, +15%PSL: 23 ± 3.7 N/Kg, -15%PSL: 23 ± 2.6 N/Kg) conditions. Planned comparison between the conditions determined that -15%PSL and PSL were different ($p = 0.016$) and +15%PSL and PSL were also different ($p = 0.024$). However, -15%PSL and +15%PSL conditions were not different ($p = 0.813$) from each other.

Figure 13

Figure 13: Illustration of active peak (AP) (N/Kg) across three stride length conditions. Active peak was different ($p < 0.05$) between the stride length conditions.

CHAPTER V

DISCUSSION

The purpose of the study was to quantify shock attenuation and impact characteristics for children (boys and girls) running with different stride lengths. This is the first attempt to quantify shock attenuation and impact characteristics in children running. There are no previous shock attenuation data for children running with which present study can be compared. However, studies have been done on adults where shock attenuation was quantified (Derrick, Hamill & Caldwell, 1998; Mercer, Devita, Derrick & Bates, 2003; Mercer, Bezodis, Russell, Purdy & DeLion, 2005) and impact characteristics were quantified (Derrick, Hamill & Caldwell, 1998; Derrick, Caldwell & Hamill, 2000; Mercer, Bezodis, Russell, Purdy & DeLion, 2005) while manipulating stride lengths. Nevertheless, since the anatomy and morphology of children is different from that of adults (Rice, Waniewski & Maharam, 2003) it is difficult to compare running in children and adults.

Shock Attenuation and Stride Length

The hypothesis that shock attenuation will change with different stride lengths for children is refuted by these results. Shock attenuation was not different between the stride length conditions in child runners. In adults the relationship between shock attenuation and stride length has been well established (Mercer, Vance, Hreljac, & Hamill, 2002;

Mercer, Bates, Dufek, & Hreljac, 2003; Mercer, Bezodis, Russell, Purdy, & DeLion, 2005). Shock attenuation increases with increasing stride length (Mercer, Vance, Hreljac, & Hamill, 2002; Mercer, Bates, Dufek, & Hreljac, 2003) among adult runners. In the present study, the trend ($p = 0.053$) for shock attenuation in the time domain suggests that shock attenuation increased with increasing stride length in children. Mathematically, shock attenuation in the time domain is calculated by the ratio between peak impact acceleration of the head and leg. This increasing trend in shock attenuation was due to an increase in mean values of the peak leg impact acceleration however, statistically ($p = 0.213$) peak leg impact acceleration was not different between the conditions and there was no change in peak head impact acceleration between the conditions. Children shock attenuation was not different in the frequency domain analysis. The frequency ranged analyzed was 11-20Hz. This frequency range should capture the frequencies associated with the impact phenomenon (Derrick, Hamill, & Caldwell, 1998; Mercer, Devita, Derrick, & Bates, 2003; Nigg, Cole, & Bruggemann, 1995; Winslow & Shorten, 1989). No analysis was completed above 20 Hz because minimal power existed in both PSD_{leg} and PSD_{head} profiles above this level. Mathematically, shock attenuation in the frequency domain is calculated by the ratio between power spectral density of the head and leg data. PSD_{head} ($p = 0.163$) and PSD_{leg} were not different ($p = 0.124$) between the stride length conditions which could be a possible explanation for no difference in shock attenuation in frequency domain.

Impact Peak and Stride Length

The hypothesis that impact peak will change with different stride lengths for children is refuted by the results. Impact peak was not different between the stride length conditions in children. According to some authors, An adult's impact peak increases with increasing stride length (Derrick, Hamill, & Caldwell, 1998; Derrick, Caldwell, & Hamill, 2000) while others observed that impact peak was not different between running with preferred stride length and longer stride length due to increased knee contact angle (McMahon, Valiant, & Frederick, 1987). Derrick (2004) reported a decrease in impact peak by increasing knee contact angle. He explains it by the mechanism of effective mass. According to Newton's second law, force is the function of both mass and acceleration of the body. Decrease in mass and/or decrease in acceleration can reduce force. According to Derrick (2004) increase in stride length causes increase in knee flexion during contact which reduces the effective mass of the body that result in reducing impact. The relationship between knee angle and effective mass has been well established (Denoth J., 1986; Derrick, 2004; Gerritsen, Van den Bogert, & Nigg, 1995). So by reducing the effective mass of the body the magnitude of the impact force can be decreased. This can be achieved by changing the stride length.

Loading Rate and Stride Length

The hypothesis that loading rate will change with different stride lengths for children is refuted by the results. Loading rate was not different between the stride length conditions in children. In adults loading rate increases with increasing speed (Munro, Miller, & Fuglevand, 1987), and it is well established that an increase in speed is

accompanied by increasing stride length (Mercer, Vance, Hreljac, & Hamill, 2002). So it can be inferred from the above studies that loading rate increases with increasing stride length in adult runners. The present study suggests a trend ($p = 0.065$) that loading rate increased with increasing stride length in children which is in agreement with the literature on adults (Mercer, Vance, Hreljac, & Hamill, 2002; Munro, Miller, & Fuglevand, 1987). On performing planned comparison it was observed that loading rate was different when there was 30% difference in stride length.

Active Peak and Stride Length

The hypothesis that active peak will change with different stride lengths for children is tenable by the results. Active peak was different between the stride length conditions in children. On observing the mean values of the three conditions it is evident that active peak decreased when the stride length was changed from PSL. On performing planned comparison it was observed that active peak decreased when there was 15% change in stride length. In adults too, it was reported that the active peak was decreased when changed from PSL (McMahon, Valiant, & Frederick, 1987). According to McMahon, (1987) the decrease in active peak is due to increased knee flexion which results in decreasing the effective vertical spring stiffness of the body. McMahon et al. (1987) investigated the mechanics of running to determine the effect on the vertical stiffness of the body, which serves to reverse the downward velocity of the body during one contact period. They showed this stiffness increases with running speed, and that at any speed, the stiffness may be reduced in a controlled fashion by running with the knees bent more than usual. McMahon et al. (1987) reported that running with the knees bent

reduces the effective vertical stiffness and diminishes the transmission of mechanical shock from the foot to the skull. Results of the present study indicated that the active peak decreased by changing the stride length compared to PSL in child runners which is in agreement with that of adult runners.

Single Subject Responses

Target stride length was achieved by eight out of ten subjects. For +15%PSL condition, subjects as a group achieved 14.11 ± 2.65 % and for -15% PSL condition subjects achieved 11.19 ± 2.74 % as mean stride length. The acceptable range was -5% to +5% of the target stride lengths in both the conditions. Inspection of individual data sets led to the observation that two subjects did not achieve the target stride length conditions. One subject was only able to achieve 4.6% of the target stride length for -15%PSL condition. Similarly, another subject was only able to achieve 9.4% of the target stride length for -15% PSL condition, which was not expected prior to the experiment. The statistical tests were run with and without the means of these two subjects. It was observed that there was unnoticeable change in the statistical values (for SA, when $n = 10$; $p = 0.053$, when $n = 8$; $p = 0.175$) for all the three conditions and the results from statistical tests for eight subjects were no different from the results of ten subjects. Even the trend observed in the dependent variables did not change when the data for these two subjects were excluded. Based upon these analyses it is concluded that inclusion of the subjects did not influence the statistical outcome. Therefore, data for all ten subjects were included in the analyses.

Within Subject or Intra-subject Variability

As stated earlier, eight subjects achieved the target stride length for both conditions. The means for achieved stride length of one subject was very close (-15%PSL: 14.42%, +15%PSL: 14.65%) to the target stride lengths. When the individual trials of these means were analyzed for -15%PSL, out of ten good trials only 6 trials and for +15%PSL only 4 trials were in the range. It can be observed from this analysis that although the means for these subjects were almost close to the target stride length, the individual trials were all above as well as below the range. Similar is the case for other three subjects whose means were in the range, but almost half of the individual trials were not in the acceptable range. In contrast to this, there were four other subjects whose most of the individual trials as well as the mean were within the acceptable range. So it can be concluded from analyzing all the subjects individually that there was very high within subject or intra-subject variability which might have an effect on the group results as a whole.

Between Subject Variability

Along with intra-subject variability, between subject variability was also qualitatively high (Figure 14). In the case of shock attenuation there were four different responses from ten subjects. For four subjects, a linear response of shock attenuation across stride length was observed. Shock attenuation increased with increasing stride length. For three subjects shock attenuation increased when stride length was either increased or decreased relative to preferred stride length. For two subjects, shock attenuation decreased with increasing stride length and for one subject shock attenuation

decreased when the stride length was either increased or decreased relative to preferred stride length. The high variability between subjects could be due to the difference in the height of the subjects which may have an effect on their stride lengths. Different level of running experience would also have added to this variability, since all the subjects were recreational runners. In addition, all the subjects may be in growth spurt period which might have affected the variability.

Figure 14

Figure 14: Illustration of shock attenuation across the actual stride lengths achieved by the subjects.

Since this study is the first attempt to quantify shock attenuation and impact characteristics (impact peak, active peak and loading rate) in child runners, it is very difficult to predict the relationship between shock attenuation and stride length as well as impact characteristics and stride length based upon one single study.

Based upon the present study it seems that shock attenuation and loading rate are statistically not different across the three stride length conditions but, results observed for active peak are similar to those of adults. These findings suggest that children may

manage shock and impact differently from that of adults. The reasons for having these differences between children and adults could be many. One reason may be the difference in the anatomy and morphology of the two groups. Children have a growth spurt period which is common in the age group of subjects chosen for the present study. During this time, rapid changes in the length, mass and moment of inertia of the extremities occur (DiFiori, 2002; Hawkins & Metheny, 2001). This may result in difference in the lower extremity geometry among children. These differences would have resulted in within subject or intra-subject variability and between subject variability, which was high among these child runners. Figure 14 illustrates a high between subject variability for shock attenuation. The reason may be that children run with shorter stride lengths and slow speed as compared to adult runners. Future investigations on child runner performance, focusing on variability as well as comparative adult patterns, are warranted. In addition, subjects in this study ran at a speed of 3m/s, while in most of the adult running studies the subjects ran at speed of 3-6m/s (Mercer, Vance, Hreljac, & Hamill, 2002; Mercer, Devita, Derrick, & Bates, 2003; Derrick, Hamill, & Caldwell, 1998). It is a well known fact that shock attenuation and impact forces changes with change in speed (Mercer, Vance, Hreljac, & Hamill, 2002; Mercer, Devita, Derrick, & Bates, 2003; Derrick, Hamill, & Caldwell, 1998). There might be a possibility, that this difference in speed would have caused differences in results. Comparative studies should be performed for children and adults running at same speed in the future to establish the relationship between shock attenuation and stride length as well as impact characteristics and stride length in children.

Based upon the knowledge gained from this study it can be concluded that during running children may manage shock and impact differently from adults as well as one child manage shock and impact different from another. It can be concluded that, while designing a training method for children, the variability issue should be taken into consideration.

Limitations of the Study

This high intra-subject and within subject variability are considered to be the main limitations of the study which were not anticipated during the experiment. Another limitation which would have added to this high variability would be the novelty of the experiment for the subjects. These subjects never ran the way they were asked to run for this experiment in order to manipulate the stride lengths. These limitations may have contributed towards the high variability observed within the subject. Future investigations on child runner performance, focusing on variability as well as comparative adult patterns, are warranted. In addition all our subjects were physically active children involved in one or the other sports. If only runners would be taken for the study, this may reduce this variability.

Conclusion

This study was designed to better understand the effect of changes in stride length on shock attenuation and impact characteristics in children. In conclusion shock attenuation and impact peak did not change with the change in stride length in children.

However, loading rate increased with 30% increase in stride length and active peak was decreased with 15% change in stride length in child runners.

Summary of the Study

There are benefits of running to improve general fitness by inducing physiological stress and/or psychological well being. Although the exact mechanism of overuse running injuries is not fully understood, this type of injury occurs when runners undergo repetitive forces generated between the foot and the ground. One hypothesis addressing overuse injuries is that the magnitude of impact force during stance phase of running is associated with injuries. Shock attenuation is a biomechanical measure used to understand how this impact is managed by the body. Due to an increase in organized sports in children, these overuse injuries are becoming common in this age group also. There is vast literature on impact and shock attenuation in adults. However, very limited research has been done on children in this research area. The purpose of this study was to quantify shock attenuation (time and frequency domain) and impact characteristics (impact peak, active peak and loading rate) for children (boys and girls) running with different stride lengths. It was observed that shock attenuation in time and in the frequency domain and impact peak was not influenced by stride length. Loading increased when there was 30% increase in stride length. Active peak decreased between the stride length conditions. Intra subject and within subject variability were the main confounding factor of the study. Future investigation should be done focusing on this issue.

APPENDIX A

FORMS AND MATLAB PROGRAMS

University of Nevada, Las Vegas

Department of Kinesiology

Parental Consent for Minor

TITLE OF STUDY: Shock Attenuation Characteristics for children running at different Stride lengths.

CONTACT INFORMATION

If you have any questions or concerns about the study, please contact:

Dr. John Mercer 895-4672

Dr. Janet Dufek 895-0702

Kunal Bhanot 895-4494

For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted you may contact **the UNLV Office for the Protection of Research Subjects at 895-2794.**

Purpose of the Study

The purpose of this study is to better understand children running patterns. Specifically, we are looking at what we call 'impact characteristics' during running. In short, we are interested in what happens when the foot collides with the ground with each step during running. In adults, we have a very good understanding of the impact characteristics during running and how the impact is attenuated, which we refer to as 'shock attenuation.' However, we have very little information regarding impacts and shock attenuation for children runners. We think this is important to study since we believe that the impact might be important in causing overuse running injuries. Therefore, the purpose of this study is to learn more about shock attenuation by investigating its characteristics during running with different stride lengths in children runners.

Participants

Your child has been asked to participate in this study because he/she is physically active, is free from injury and is between 9 and 12 years old. In order for your child to participate in the study, you and your child must provide written consent.

The purpose of this document is to provide you with information about what your child will be asked to do as well as the risks associated with participating in the study. You are encouraged to ask questions about the study. If your child participates in the study, you will be required to be present during all testing and you or your child has the right to stop the test with no prejudice to you or your child. Your child must not suffer from any injury that would interfere with his/her ability to run.

Procedure

If your child participates in the study, we will place some instruments on his/her leg and head. These instruments record accelerations and are about the size of a pencil eraser (see the picture at the end of this document). To place the accelerometer on the leg, we

will use a combination of elastic wrapping and athletic tape. To place the accelerometer on the head, we will ask your child to wear a plastic head gear, similar to a hat band. In both cases, we will try to secure the accelerometers as tightly as possible.

Once instrumented, your child will be asked to run on overground at different stride lengths. The stride length will range from preferred stride length (PSL) which is defined as the freely chosen stride length at a running velocity of 3 m/s (about 6-7 mph). Your child will run in three stride length conditions: PSL, 15% longer stride length and 15% shorter stride length. In all conditions the normal progression velocity will be 3 m/s. To achieve the longer and shorter stride length conditions, we will place markers on the runway. We will try to collect a total of 10 trials for each stride length condition, where a 'good' trial is one where the correct speed was achieved, the correct stride length was used, and the foot struck the force platform (this is an instrument placed in the floor). We will keep track of the number of attempts and will move on to the next condition when your child reaches 20 attempts (regardless if 10 good trials have been collected). Throughout the data collection session, water and non carbonated beverages will be provided to the child if he/she wants to have a drink.

During all tests, your child will have time to rest in between trials. It will take about 1-1.5 hours to get everything ready, have your child run, and then unhook your child from the equipment.

Benefits of Participation

There may not be direct benefits to you or your child as a participant in this study. By being part of the study, your child will see how research is conducted in the Biomechanics Laboratory. Also, we will learn more about how children his/her age run at different stride lengths.

Risks of Participation

There are risks involved in all research studies. This study may include only minimal risks.

As in any running activity there is always the chance that your child might be sore after testing – but this will likely be similar to the soreness your child might have after a physical education class. We can help minimize any muscle soreness by giving him ample rest in between trials.

Cost /Compensation

There will not be financial cost to you to participate in this study. The study will take about 1-1.5 hours on the day of your time. You will not be compensated for your time, but if you need a parking pass, please let us know and we will provide one to you. *The University of Nevada, Las Vegas may not provide compensation or free medical care for an unanticipated injury sustained as a result of participating in this research study.*

Contact Information

If you have any questions or concerns about the study, you may contact John Mercer, Ph.D. at 895-4672. For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted you

may contact the UNLV Office for the Protection of Research Subjects at 702-895-2794.

Voluntary Participation

Your child's participation in this study is voluntary. If at any time you do not want him/her to continue or if he/she does not want to continue with the study, please let us know and the test will stop. Prior to your child signing the 'Assent Form', he/she must discuss the study with you. We want you and your child to ask any questions either of you may have about the study prior to signing this document. If your child does participate in the study, we will provide copies of both forms.

Confidentiality

All information gathered in this study will be kept completely confidential. No reference will be made to your child's name or any other information that would allow someone else to link your child to this study. All records will be stored in a locked facility at UNLV for 3 years after completion of the study and identifiable information destroyed thereafter.

Consent

I have read the above information and agree to have my child participate in this study. A copy of this form has been given to me.

Signature of Parent

Date

Participant Note: Please do not sign this document if the Approval Stamp is missing or is expired.

Signature of Researcher

Date

Principal Investigators:

John A. Mercer, Ph.D.

Janet Dufek, Ph.D.

Kunal Bhanot

<p>Illustration of hat band worn during testing.</p>
<p>Illustration of tape securing an accelerometer on the left leg.</p>

ASSENT TO PARTICIPATE IN RESEARCH

TITLE OF STUDY: Shock Attenuation Characteristics for children running at different Stride lengths.

1. My name is Kunal Bhanot, I am a graduate student in department of Kinesiology at UNLV. I work under Dr. John Mercer, who works at UNLV with a group of other researchers and we study how people run.
2. We are asking you to take part in a research study because we are trying to learn more about how children run. In order for you to be part of this study, you must be physically active, free from injury and be between 9 and 12 years old.
3. If you agree to be in this study we'll ask that you run at different stride lengths. In some cases, we'll ask that you run however you normally would. In other cases we will ask you to run while hitting specific markers on the ground. Before you start running, we'll put some different instruments on your body so that we can measure different things to see how you run. A picture of these instruments is included with this form. The instruments are small (about the size of a pencil eraser). One will be wrapped around your leg. The other is attached to a head-gear (sort of like wearing a hat).
4. Sometimes people are sore after running. The running that we will ask you to do would be similar to what you may do in a physical education class at school.
5. By being part of this study we hope that you learn more about research. We also hope to learn more about how children run.
6. Please talk this over with your parents before you decide whether or not to participate. We will also ask your parents to give their permission for you to take part in this study. But even if your parents say "yes" you can still decide not to do this.
7. If you don't want to be in this study, you don't have to participate.
8. You can ask any questions that you have about the study. If you have a question later that you didn't think of now, you can call me 895-3289 or Dr. John Mercer 895-4672 or ask me next time or have your parents call me.
9. Signing your name at the bottom means that you agree to be in this study. Remember, being in this study is up to you and no one will be upset if you don't want to participate or even if you change your mind later and want to stop. You and your parents will be given a copy of this form after you have signed it.

Print your name

Date

Sign your name

Picture of hat band worn during testing.

Picture of an instrument attached to the left leg.

Shock Attenuation in Children Running @ different Stride Lengths

Project Organizer Document

Date of Consent	
Test Date	
Subject ID #	
Date of Birth / Age	
Weight	
Height	
Location of Files	
Velocity	3 m/s

Over Ground			Condition 1 (PSL)			Condition 2 (+15%PSL)			Condition 3 (-15%PSL)		
Range (2.85 m/s - 3.15 m/s)			Range (2.85 m/s - 3.15 m/s)			Range (2.85 m/s - 3.15 m/s)			Range (2.85 m/s - 3.15 m/s)		
Trial	Speed	Accepted (Yes/No)	Trial	Speed	Accepted (Yes/No)	Trial	Speed	Accepted (Yes/No)	Trial	Speed	Accepted (Yes/No)
1			1			1			1		
2			2			2			2		
3			3			3			3		
4			4			4			4		
5			5			5			5		
6			6			6			6		
7			7			7			7		
8			8			8			8		
9			9			9			9		
10			10			10			10		
11			11			11			11		
12			12			12			12		
13			13			13			13		
14			14			14			14		
15			15			15			15		
16			16			16			16		
17			17			17			17		
18			18			18			18		
19			19			19			19		
20			20			20			20		
Good Trials			Good Trials			Good Trials			Good Trials		

MATLAB PROGRAMS USED FOR DATA ANALYSIS

1. Kunal thesis program.m (Main program for data analysis)
2. OG_open.m (To open an input data file)
3. OGFz1.m (Calculate impact peak and active peak)
4. TMSA.m (calculate shock attenuation)
5. TMSL.m (calculate stride length and stride frequency)
6. OGleg.m (calculate impact peak acceleration of leg)
7. OGTMhead.m (calculate impact peak acceleration of head)
8. my_save.m (save outputfile)
9. psdanalysis1 (power spectral density analysis)

Kunal thesis program.m (Main program for data analysis)

```
%kunalthesisprog.m
%This program calculates Impact peak and Active peak of vGRF
%It calculates Loading rate from the slope of impact peak
%Leg and Head Acc, SA, SF and SL
%Written Spring 2007
%
%Files called include:
%
%

clc
clear;
clear all;
fclose('all');

temporary_directory = pwd;
fprintf(1,'\n\nProcessing\n\n');

%=====
%    Change the following parameters
%    prior to running program
%=====
```

```

subjects      = 1; %number of subjects to process
conditions    = 1; %number of conditions per subject
trials        = 1; %trials per condition
startwithsubj = 1; %subject number to start with
startwithcond = 1; %condition number to start with (there were 6 conditions)
startwithtrial = 1; %trial number to start with

directory      = 'c:\biomech\Thesis\SA\Thesisdata\Subject3\' ; %directory where data
is located
outputfile     = 's8c3out10.txt';

precision      = 4;          %output precision
searchwindow   = 50;         %number of points for searching max

savedata       = 'yes';
savefiles      = 'no';

runningspeed   = 2.89;       %in m/s

%=====
%   Don't change anything after this point
%=====

bioheaders     = 13;
biofs          = 1000;
biocol         = 8;

%=====

alldata=[];
filenumber = 0;

for s = startwithsubj:(startwithsubj+subjects-1)
    for c = startwithcond:(startwithcond+conditions-1)
        for t = startwithtrial:(startwithtrial+trials-1)

            %keep loop counter
            filenumber = filenumber+1;

            %open a file
            [biodata, inputfile] = OG_open(s, c, t, 'b', directory, '.txt', '.aot', biocol, inf,
            bioheaders);

            %assign variables from bioware

```

```

heada    = biodata(:,2);
lega     = biodata(:,3);
biotime  = biodata(:,1);
lighton  = biodata(:,5);
lightoff = biodata(:,4);
Fx       = biodata(:,6);
Fy       = biodata(:,7);
Fz       = biodata(:,8);

%      Ask for the running speed

fprintf(1,'\n');
runningspeed = input('What is the running speed? ');
fprintf(1,'\n');

%      Identify impact peak and active peak
OGFz1

%      Identify leg acc, head acc, SA, SF and SL
kidsOGSAbackup

%      Calculate load rate
%      loadrate

for i = 1:length(headpeak)
    ss(i) = s;
    cc(i) = c;
    tt(i) = t;
end

%      compile data for overground running condition
if t - startwithtrial == 0
    st = 1;
    ed = npeaks-1;
else
    st = npeaks + st -1;
    ed = npeaks + ed-1;
end

%      Compile all the data

```

```

        alldata(st:ed,1:11) = [ss' cc' tt' maxFz(1:npeaks-1)' legpeak(1:npeaks-1)'
peakpos(1:npeaks-1)'/biofs headpeak' headpeakpos'/biofs tmsa' tmsf' tmsl']

        clear ss cc tt;

        end          %next trial
    end %next condition
end %next subject

%output data using a function 'my_save'
if strcmp(savedata, 'yes')
    my_save(directory, outputfile, alldata, precision);
end

%change back to original directory
eval(['cd ' temporary_directory])

%clean house
close(gcf);
fclose('all');

%identify done processing
fprintf(1, '\ndone\n\n');

%-----clean up-----
%                clear;

```

OG_open.m (To open an input data file)

```

%function: OG_open
%this function will run the commonly used commands to open a file.
%
%called as:
%    data = OG_open(s, c, t, datatype, directory, datain, dataout, columns, rows,
headers)
%
%where
%    directory    = location of file
%    filename     = name of file with extension
%    columns      = number of columns
%    rows         = number of rows
%    headers      = number of headers to get rid of

```

```

function [tempdata, inputfileroot] = OG_open(s, c, t, datatype, my_dir, datain, dataout,
columns, rows, headers);

    %create s?c?t? filename
    subj = int2str(s);
    cond = int2str(c);
    tri = int2str(t);

    f_name = ['s' subj 'c' cond 't' tri datatype];
    fprintf(1,f_name); fprintf(1,'\n');
    inputfileroot = f_name;

    %create filenames
    inputfile      = [f_name datain];    %*.prn
    grfout         = [f_name dataout];   %*.grf

    %my_dir = data directory
    %inputfile = filename with extension
    %columns = number of columns
    %headers = number of headers to discard

    %set up commands for eval function
    %change to working directory
    eval(['cd ' my_dir ';']);

    %open the file
    %create substrings
    c = 'fid=fopen(';
    d = '", "rt")';

    %create filename
    file_name = [c, inputfile, d];

    %open peak input file
    eval(file_name);

    %check to see if the open was successful
    if fid == -1
        clc
        message = ['The filename ' inputfile ' does not exist in directory ' my_dir];
        error(message);
        fprintf(1,'\n\n');
    end

```

```

    %get rid of headers
    for h = 1:headers
        fgets(fid);
    end

    %read in data
    A = fscanf(fid, '%f', [columns rows]);
    tempdata = A';

    %close files
    fclose('all');

```

OGFz1.m (Calculate impact peak and active peak)

```

%OGFz1
%
%Identify impact peak and active peak
%

fprintf(1, '\nIdentify ');
% fprintf(1, int2str(npeaks));
fprintf(1, 'Fz peaks. ');

figure('position', [100 80 1000 400])
Fzsearchwindow = 10;

% plot vGRF with time
plot(biotime, Fz, 'k');
hold on
ylabel('Vertical GRF (N)')
xlabel('time (s)')
title('Vertical GRF during OG running')

% number of peaks needed
npeaks = 2;

%find peaks
numberofpeaks = npeaks;
fprintf(1, '\n');

for i = 1:numberofpeaks

    %get graph information
    [xpos, ypos] = ginput(1);

```



```

xpos      = round(xpos*biofs);

%identify start and end point to search for max
start      = xpos - searchwindow;
endsearch  = xpos + searchwindow;

%check for searching beyond data set
if (start<1)
    start=1;
end

if (endsearch>length(Fz))
    endsearch = length(Fz);
end

% get the extracted data
newdata = Fz(start:endsearch);
newtime = biotime(start:endsearch);

%plot the extracted data
plot (newtime, newdata);

% Find max value and max position of the extracted data
[maxFz(i), tempmaxFz_pos(i)] = max(newdata);

% Adjust the position of the max value of the extracted data to the original
% data

maxFz_pos(i) = tempmaxFz_pos(i) + xpos - searchwindow - 1;

plot (biotime(maxFz_pos(i)),Fz (maxFz_pos(i)), 'ro');

end

pause (1.0)
close (gcf)

```

TMSA.m (calculate shock attenuation)

```

%TMSA
%
%calculate shock attenuation during treadmill running
fprintf(1, '\nShock attenuation calculated.')

for i = 1:npeaks-1

```

```

    tmsa(i) = (1-headpeak(i)/legpeak(i))*100;

end

meantmsa = mean(tmsa);
sdtmsa = std(tmsa);

TMSL.m (calculate stride length and stride frequency)

%TMSL
%
%Calculate stride length while running on treadmill
%
%v = SL*SF
%

%calculate stride frequency
fprintf(1,'\nStride parameters (SL, SF) calculated.')

%transform position to time

for i = 1:npeaks-1
    stridetime(i) = peakpos(i+1)-peakpos(i);
end

stridetime = stridetime./biofs;
tmsf = 1./stridetime;

meantmsf = mean(tmsf);

sdtmsf = std(tmsf);

%calculate stride length
for i = 1:npeaks-1
    tmsl(i) = runningspeed/tmsf(i);
end

meantmsl = mean(tmsl);

clear stridetime;

```

OGleg.m (calculate impact peak acceleration of leg)

```
%OGleg
%
%Identify leg peaks during running on treadmill
%

fprintf(1,'\nIdentify ');
fprintf(1,int2str(npeaks));
fprintf(1,' leg peaks.');
```

figure('position', [100 80 1000 400])

subplot(2,1,1)
plot(biotime, lighton)
hold on
plot(biotime, lightoff)
hold off

subplot(2,1,2)
plot(biotime,lega, 'k');
hold on
ylabel('leg acceleration (g)')
xlabel('time (s)')
title('Leg Acceleration During Treadmill Running')

%find peaks
numberofpeaks = npeaks;
fprintf(1,'\n');

for i = 1:numberofpeaks

 %get graph information
 [xpos, ypos] = ginput(1);
 xpos = round(xpos*biofs);

 %identify start and end point to search for max
 start = xpos - searchwindow;
 endsearch = xpos + searchwindow;

 %check for searching beyond data set
 if (start<1)
 start=1;
 end

 if (endsearch>length(lega))

```

        endsearch = length(lega);
    end

    legpeak(i) = max(lega(start:xpos+searchwindow));
    temppeakpos = find(lega(start:xpos+searchwindow)==legpeak(i));
    temppeakpos(2) = 0;
    peakpos(i) = temppeakpos(1);
    peakpos(i) = peakpos(i) + (start)-1;

    plot(biotime(peakpos(i)),lega(peakpos(i)), 'ro')
    drawnow

end
pause(0.5)
close(gcf)

```

OGTMhead.m (calculate impact peak acceleration of head)

```

%OGTMhead
%
%Identify head peaks during running on treadmill
%

fprintf(1,'\nIdentify head peak for first leg peak.')

figure('position', [100, 300, 500, 500])
headsearchwindow = 50;

for i = 1:npeaks-1

    startplot = peakpos(i)-100;
    endplot = peakpos(i+1)+100;

    %plot
    subplot(2,1,1)
    plot(biotime(startplot:endplot),lega(startplot:endplot),'k')
    hold on
    plot(biotime(peakpos(i)),lega(peakpos(i)), 'ro')
    plot(biotime(peakpos(i+1)),lega(peakpos(i+1)), 'ro')
    hold off
    title('Leg Acceleration')
    ylabel('Acceleration (g)')

    subplot(2,1,2)
    plot(biotime(startplot:endplot),heada(startplot:endplot),'k')

```

```

hold on
title('Head Acceleration')
ylabel('Acceleration (g)')
xlabel('Time (s)')

%find head peak
%get graph information
[xpos, ypos] = ginput(1);
xpos        = round(xpos*biofs);

%identify start and end point to search for max
start        = xpos - headsearchwindow;
endsearch    = xpos + headsearchwindow;

%check for searching beyond data set
if (start<1)
    start=1;
end

if (endsearch>length(lega))
    endsearch = length(lega);
end

headpeak(i)  = max(heada(start:xpos+headsearchwindow));
temppeakpos  = find(heada(start:xpos+headsearchwindow)==headpeak(i));
temppeakpos(2) = 0;
headpeakpos(i) = temppeakpos(1);
headpeakpos(i) = headpeakpos(i) + (start)-1;

plot(biotime(headpeakpos(i)),heada(headpeakpos(i)), 'ro')
drawnow
pause(0.1)
hold off

end

close(gcf)

```

my_save.m (save outputfile)

```

%Function: my_save(directory, filename, data, precision)
%
%This function will save data to a specified file with a specified precision
%

```

```

function my_save(directory, filename, data, precision)

    %initialize variable
    all_column_info = [];

    %change directory
    temp = pwd;
    eval(['cd ' directory]);

    %open the file to write to
    fid=fopen(filename, 'w');

    %make quote notation
    q='\"';

    %check the size of the data array
    [rows columns] = size(data);

    %Create the necessary write commands

    column_precision = int2str(precision);
    column_info = ['%5.' column_precision 'f'];

    for i = 1:columns
        all_column_info = [column_info ' ' all_column_info];
    end

    %transpose the output data array because the print command writes
    %column 1, then column 2, ...
    data=data';

    %create command line
    print_command = ['fprintf(fid,' q all_column_info '\n' q ', data);'];

    %save data
    eval([print_command]);

    %close file
    fclose(fid);

    %change back to original directory
    eval(['cd ' temp]);
psdanalysis1 (power spectral density analysis)

    clc
    clear;

```

```

clear all;
fclose('all');

temporary_directory = pwd;
fprintf(1,'\n\nProcessing\n\n');

%=====
%      Change the following parameters
%      prior to running program
%=====

subjects      = 1; %number of subjects to process
conditions     = 1; %number of conditions per subject
trials         = 1; %trials per condition
startwithsubj  = 3; %subject number to start with
startwithcond  = 1; %condition number to start with (there were 6 conditions)
startwithtrial = 19; %trial number to start with

directory      = 'c:\biomech\Thesis\SA\Thesisdata\Subject3\'; %directory where data
is located
outputfile     = 'extracted1.txt';

precision      = 4;      %output precision
searchwindow   = 512;    %number of points for searching max
fs = 1008;

savedata       = 'yes';
savefiles      = 'no';

%=====
%      Don't change anything after this point
%=====

bioheaders     = 13;
biofs          = 1000;
biocol         = 8;
% Fzcutoff     = 100;

%=====

alldata=[];
filenumber = 0;

for s = startwithsubj:(startwithsubj+subjects-1)
    for c = startwithcond:(startwithcond+conditions-1)
        for t = startwithtrial:(startwithtrial+trials-1)

```

```

%keep loop counter
filenumber = filenumber+1;

%open a file
[biodata, inputfile] = OG_open(s, c, t, 'b', directory, '.txt', '.aot', biocol, inf,
bioheaders);

%assign variables from bioware
heada = biodata(:,2);
lega = biodata(:,3);
biotime = biodata(:,1);
lighton = biodata(:,5);
lightoff = biodata(:,4);
Fx = biodata(:,6);
Fy = biodata(:,7);
Fz = biodata(:,8);

subplot (2,1,1)
plot (biotime, lighton)
hold on
plot (biotime, lightoff)
hold off

subplot (2,1,2)
plot (biotime, lega)

[xpos, ypos] = ginput(1);

clickedposition = round(xpos*biofs);

startsearch = clickedposition-searchwindow;
if startsearch < 0
    startsearch = 1;
end

endsearch = clickedposition+searchwindow;

if endsearch > length(lega)
    endsearch = length(lega);
end

%creat new plot
newdata = lega(startsearch:endsearch-1);
newtime = biotime(startsearch:endsearch-1) - biotime(startsearch);
newhead = heada(startsearch:endsearch-1);

```



```

%      pause
%close subplot
close(gcf)

%plot extracted data
plot (newtime, newdata);
ylabel('acceleration (g)')
xlabel('time (s)')
hold on

%find min
[hcmin] = myfindmin(newtime, newdata, fs, 10);

%plot
plot(newtime(hcmin), newdata(hcmin), 'ro')
drawnow

[tomin] = myfindmin(newtime, newdata, fs, 10);
plot(newtime(tomin), newdata(tomin), 'ro')
drawnow
hold off

%      pause
%extract data
finaldata = newdata(hcmin:tomin);
finalhead = newhead(hcmin:tomin);
finaltime = 0:1/fs:(length(finaldata)-1)/fs;

ylabel('leg (g)') )
xlabel('time (s)')e, finaldata)
ylabel('leg (g)')
xlabel('time (s)')
hold on

subplot(2,1,1)
plot(finaltime, finalhead)
ylabel('head (g)')
hold on

%-----

points = 1024;

%-----
%      Get times and adjust so that

```

```

%          There is a variable that starts at '1' and
%          ends with end_t as some whole number
%-----
%remove linear trend
%identify first and last data points
%calculate slope
legslope = (finaldata(end) - finaldata(1))/(finaltime(end) - finaltime(1));
headslope = (finalhead(end) - finalhead(1))/(finaltime(end) - finaltime(1));

%create data set for line
legline = finaltime.*legslope;
headline = finaltime.*headslope;

%remove linear trend
finaldata_lin = finaldata - legline;
finalhead_lin = finalhead - headline;

subplot(2,1,2)
plot(finaltime, finaldata_lin, 'r')
subplot(2,1,1)
plot(finaltime, finalhead_lin, 'r')

%remove mean trend
finaldata_mean = finaldata_lin - mean(finaldata_lin);
finalhead_mean = finalhead_lin - mean(finalhead_lin);

%plot
subplot(2,1,1)
plot(finaltime, finalhead_mean, 'g')
subplot(2,1,2)
plot(finaltime, finaldata_mean, 'g')

%calculate power spectrum
[legpower,f]=psd(finaldata_mean, points, 1000, boxcar(points));
[headpower,f]=psd(finalhead_mean, points, 1000, boxcar(points));

%because zeros are padded to the data, the power needs to
%be adjusted as per Shorten & Winslow and Derrick et al.

adjust = (length(finaldata_mean)+(points-length(finaldata_mean))
)/length(finaldata_mean);
legpower = legpower.*adjust;
legpower = legpower.*(1000/points);

headpower = headpower.*adjust;
headpower = headpower.*(1000/points);

```

```

    lastfreq = 100;
    subplot(3,1,1)
    plot(f(1:lastfreq),legpower(1:lastfreq))
    subplot(3,1,2)
    plot(f(1:lastfreq),headpower(1:lastfreq))
    subplot(3,1,3)
    sa = 10*log(headpower./legpower);
    plot(f(1:lastfreq),sa(1:lastfreq))

    pause (1.0)

    %calculate over frequency range
    legpowermean = mean(legpower(11:21))
    headpowermean = mean(headpower(11:21))
    samean = mean(sa(11:21))

    %-----

    % Compile all the data
    alldata(:,1:4) = [f, legpower, headpower, sa];

%    allmeandata(:,1:6) = [s c t legpowermean headpowermean samean];

    %output data using a function 'my_save'
    if strcmp(savedata, 'yes')

        %create output file name
        fileout = [inputfile outputfile];

        my_save(directory, fileout, alldata, precision);
    end

    %    clear ss cc tt;
end    %next trial
end %next condition
end    %next subject

%change back to original directory
eval(['cd ' temporary_directory])

%clean house
close(gcf);
fclose('all');
%identify done processing
fprintf(1, '\ndone\n\n');

```

APPENDIX B

RAW DATA

Descriptive Data

Subjects#	Age(yrs)	Mass (Kg)	Height (cm)
S1	12	43	154
S2	11	51	149
S3	12	37	145
S5	10	26	129.5
S6	11	62	148
S7	9	30	135
S8	11	35	148
S9	11	37	147
S10	9	38	149
S11	11	43	147
Mean	10.7	40	145.2
SD	1.1	10.3	7.3

Shock attenuation (Time domain) for ten acceptable trials per subject

Subjects #	-15%PSL		PSL		+15%PSL	
	Mean(%)	SD	Mean(%)	SD	Mean(%)	SD
S1	80.0	8.7	82.4	7.76	90.7	6.3
S2	78.6	12.0	80.1	9.57	77.8	8.5
S3	91.3	4.0	86.8	10.29	95.8	3.8
S5	89.7	7.7	92.8	5.93	95.0	3.6
S6	86.2	5.6	83.3	5.69	79.2	4.2
S7	84.7	7.0	84.7	5.03	84.1	5.5
S8	74.7	5.9	77.4	4.37	80.4	5.0
S9	85.5	3.5	82.5	4.72	87.0	4.2
S10	87.0	5.6	85.5	6.99	91.0	3.8
S11	72.4	9.1	81.1	6.11	86.6	3.6
Grand Mean	83.0	6.3	83.7	4.2	86.8	6.4

Shock attenuation (Frequency domain) for ten acceptable trials per subject

Subjects #	-15%PSL		PSL		+15%PSL	
	Mean(dB)	SD	Mean(dB)	SD	Mean(dB)	SD
S1	-42.3	7.6	-43.5	6.5	-51.5	8.1
S2	-26.9	6.1	-27.0	7.4	-26.6	2.8
S3	-50.7	8.2	-42.0	8.1	-47.6	11.5
S5	-49.6	9.9	-52.2	10.7	-40.7	10.6
S6	-29.1	4.5	-26.5	4.6	-24.7	5.0
S7	-48.8	6.3	-42.7	6.3	-47.1	6.8
S8	-38.3	6.6	-38.3	6.5	-39.7	5.8
S9	-47.1	4.7	-45.5	5.4	-48.6	5.5
S10	-41.9	7.0	-35.6	6.6	-31.0	7.8
S11	-19.5	5.9	-24.0	4.6	-29.9	4.9
Grand Mean	-39.4	10.8	-37.7	9.3	-38.8	10.0

Normalized Impact Peak for ten acceptable trials per subject

Subjects #	-15%PSL		PSL		+15%PSL	
	Mean(N/Kg)	SD	Mean(N/Kg)	SD	Mean(N/Kg)	SD
S1	12.8	2.0	15.2	1.3	12.2	1.5
S2	14.3	1.5	16.0	1.9	15.1	1.6
S3	15.1	2.4	16.3	5.5	18.4	3.2
S5	13.2	1.6	11.6	1.5	12.7	1.6
S6	19.0	1.4	17.4	1.8	20.0	2.5
S7	17.0	2.0	22.5	3.4	19.7	3.0
S8	13.3	2.6	17.9	2.4	16.0	3.5
S9	15.9	2.7	14.8	1.0	14.7	2.2
S10	13.0	1.5	12.4	3.3	12.9	1.7
S11	15.9	2.6	17.8	2.0	17.6	1.9
Grand Mean	15.0	2.0	16.2	3.1	15.9	2.9

Normalized Active peak for ten acceptable trials per subject

Subjects #	-15%PSL		PSL		+15%PSL	
	Mean(N/Kg)	SD	Mean(N/Kg)	SD	Mean	SD
S1	23.0	0.5	23.1	0.8	21.7	0.8
S2	22.3	1.7	24.2	2.1	23.5	1.5
S3	19.4	1.3	20.7	2.3	17.8	1.4
S5	20.2	0.7	21.1	1.2	18.1	1.0
S6	23.9	0.9	23.0	0.7	22.6	1.9
S7	23.6	0.9	26.3	0.9	26.5	1.4
S8	27.0	0.8	28.9	0.9	29.0	0.7
S9	26.2	0.6	26.8	0.6	26.3	0.8
S10	22.8	1.3	23.5	1.3	20.7	1.0
S11	19.8	1.0	20.4	1.1	20.6	1.0
Grand Mean	22.8	2.6	23.8	2.8	22.7	3.7

Normalized Loading rate for ten acceptable trials

Subjects #	-15%PSL		PSL		+15%PSL	
	Mean(N/Kg)	SD	Mean(N/Kg)	SD	Mean(N/Kg)	SD
S1	491.4	159.8	655.8	158.1	499.3	195.2
S2	382.4	85.0	487.7	105.5	600.6	89.0
S3	609.1	185.4	657.7	333.7	1028.5	288.1
S5	510.7	144.0	679.0	266.9	784.1	303.5
S6	727.9	114.5	698.5	131.2	620.9	72.8
S7	628.7	152.5	939.8	196.8	698.7	174.0
S8	667.1	194.8	1022.3	251.4	908.8	279.4
S9	862.7	363.6	756.6	122.5	769.5	260.9
S10	516.5	133.3	433.5	105.0	704.5	168.9
S11	536.4	215.4	474.9	85.8	748.4	388.1
Grand Mean	593.3	136.8	680.6	192.0	736.3	152.4

Achieved Stride lengths for ten acceptable trials per subject

Subjects #	-15%PSL		PSL		+15%PSL	
	Mean (m)	SD	Mean (m)	SD	Mean (m)	SD
S1	2.0	0.1	2.2	0.1	2.5	0.1
S2	2.1	0.1	2.3	0.1	2.7	0.1
S3	1.9	0.1	2.2	0.3	2.5	0.1
S5	1.8	0.1	2.0	0.1	2.3	0.1
S6	2.0	0.1	2.2	0.1	2.6	0.1
S7	1.7	0.1	2.0	0.0	2.2	0.1
S8	2.0	0.1	2.2	0.0	2.4	0.1
S9	2.0	0.1	2.3	0.1	2.5	0.1
S10	2.1	0.1	2.2	0.1	2.6	0.1
S11	1.7	0.0	1.9	0.1	2.3	0.1
Grand Mean	1.9	0.1	2.2	0.1	2.5	0.1

Achieved Stride lengths in Percentage

Subjects#	-15%PSL	+15%PSL
S1	11.7	14.6
S2	11.2	13.7
S3	14.4	14.6
S5	9.4	12.8
S6	11.1	16.4
S7	13.7	13.4
S8	10.9	9.5
S9	11.8	11.2
S10	4.6	18.7
S11	13.0	16.2
Mean	11.2	14.1
SD	2.7	2.7

APPENDIX C

SUMMARY OF STATISTICS

Statistical Analysis for Shock Attenuation (Time Domain)

Within-Subjects Factors

Measure: MEASURE_1

sl	Dependent Variable
1	lpsl
2	psl
3	gpsl

Descriptive Statistics

	Mean	Std. Deviation	N
lpsl	82.9955	6.30992	10
psl	83.6698	4.22759	10
gpsl	86.7715	6.39934	10

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
sl Sphericity Assumed	81.109	2	40.555	3.474	.053
Error(sl) Sphericity Assumed	210.147	18	11.675		

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) sl	(J) sl	Mean Difference (I-J)	Std. Error	Sig.
1	2	-.674	1.225	.595
	3	-3.776	1.895	.078
2	3	-3.102	1.383	.052

Statistical Analysis for Shock Attenuation (Frequency Domain)

Within-Subjects Factors

Measure: MEASURE_1

sl	Dependent Variable
1	LPSL
2	PSL
3	GPSL

Descriptive Statistics

	Mean	Std. Deviation	N
LPSL	-39.4039	10.82360	10
PSL	-37.7285	9.32548	10
GPSL	-38.7589	9.96811	10

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
sl Sphericity Assumed	14.282	2	7.141	.433	.655
Error(sl) Sphericity Assumed	297.149	18	16.508		

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) sl	(J) sl	Mean Difference (I-J)	Std. Error	Sig.
1	2	-1.675	1.342	.243
	3	-.645	2.167	.773
2	3	1.030	1.846	.590

Statistical Analysis for Impact Peak

Within-Subjects Factors

Measure: MEASURE_1

sl	Dependent Variable
1	LPSL
2	PSL
3	GPSL

Descriptive Statistics

	Mean	Std. Deviation	N
LPSL	14.9507	2.02982	10
PSL	16.1790	3.06394	10
GPSL	15.9288	2.87179	10

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
sl Sphericity Assumed	8.426	2	4.213	2.032	.160
Error(sl) Sphericity Assumed	37.326	18	2.074		

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) sl	(J) sl	Mean Difference (I-J)	Std. Error	Sig.
1	2	-1.228	.794	.156
	3	-.978	.495	.080
2	3	.250	.607	.690

Statistical Analysis for Active Peak

Within-Subjects Factors

Measure: MEASURE_1

sl	Dependent Variable
1	LPSL
2	PSL
3	GPSL

Descriptive Statistics

	Mean	Std. Deviation	N
LPSL	22.8155	2.56318	10
PSL	23.8061	2.82269	10
GPSL	22.6753	3.69451	10

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
sl Sphericity Assumed	7.599	2	3.799	3.694	.045
Error(sl) Sphericity Assumed	18.515	18	1.029		

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) sl	(J) sl	Mean Difference (I-J)	Std. Error	Sig.
1	2	-.991	.334	.016
	3	.140	.575	.813
2	3	1.131	.418	.024

Statistical Analysis for Loading rate

Within-Subjects Factors

Measure: MEASURE_1

sl	Dependent Variable
1	LPSL
2	PSL
3	GPSL

Descriptive Statistics

	Mean	Std. Deviation	N
LPSL	593.3029	136.83479	10
PSL	680.5770	191.98307	10
GPSL	736.3273	152.37290	10

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
sl Sphericity Assumed	103936.042	2	51968.021	3.204	.065
Error(sl) Sphericity Assumed	291977.687	18	16220.983		

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) sl	(J) sl	Mean Difference (I-J)	Std. Error	Sig.
1	2	-87.274	51.459	.124
	3	-143.024	53.487	.025
2	3	-55.750	64.990	.413

Statistical Analysis for Peak impact acceleration of leg

Within-Subjects Factors

Measure: MEASURE_1

sl	Dependent Variable
1	lpsl
2	psl
3	gpsl

Descriptive Statistics

	Mean	Std. Deviation	N
lpsl	6.0476	3.73636	10
psl	6.7845	3.04768	10
gpsl	8.1574	2.90911	10

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
sl Huynh-Feldt	22.931	1.358	16.881	1.760	.213
Error(sl) Huynh-Feldt	117.258	12.226	9.591		

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) sl	(J) sl	Mean Difference (I-J)	Std. Error	Sig.
1	2	-.737	.571	.229
	3	-2.110	1.415	.170
2	3	-1.373	1.257	.303

Statistical Analysis for Peak impact acceleration of head

Within-Subjects Factors

Measure: MEASURE_1

sl	Dependent Variable
1	lpsl
2	psl
3	gpsl

Descriptive Statistics

	Mean	Std. Deviation	N
lpsl	.8888	.44280	10
psl	1.0545	.50478	10
gpsl	.9810	.47098	10

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
sl Sphericity Assumed	.138	2	.069	2.072	.155
Error(sl) Sphericity Assumed	.599	18	.033		

a. Computed using alpha = .05

Pairwise Comparisons

Measure: MEASURE_1

(I) sl	(J) sl	Mean Difference (I-J)	Std. Error	Sig.
1	2	-.166	.061	.024
	3	-.092	.087	.316
2	3	.073	.093	.450

Statistical Analysis for leg mean power

Within-Subjects Factors

Measure: MEASURE_1

sl	Dependent Variable
1	LPSL
2	PSL
3	GPSL

Descriptive Statistics

	Mean	Std. Deviation	N
LPSL	130.1342	84.98409	10
PSL	145.8598	65.44252	10
GPSL	186.5587	99.72822	10

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
sl Sphericity Assumed	16958.076	2	8479.038	2.348	.124
Error(sl) Sphericity Assumed	64996.926	18	3610.940		

Pairwise Comparisons

Measure: MEASURE_1

(I) sl	(J) sl	Mean Difference (I-J)	Std. Error	Sig.
1	2	-15.726	18.180	.410
	3	-56.425	30.866	.101
2	3	-40.699	29.721	.204

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Abstracts:

Kunal Bhanot, John A. Mercer, FACSM, Janet S. Dufek, FACSM, Julia A. Freedman, Anthony J. House, Janet R. Griffin (2007). Effect of Change in Running Speeds on Shock Attenuation among Children *54th Annual Meeting, American College of Sports Medicine*

John A. Mercer, **Kunal Bhanot**, Janet S. Dufek, Julia A. Freedman, Anthony J. House, Janet R. Griffin (2007). Quantification and comparison of SA characteristics for children running on treadmill and over ground *58th Annual Meeting, National Athletic Trainer's Association*

Kunal Bhanot, John A. Mercer, FACSM, Janet S. Dufek, FACSM, Julia A. Freedman, Anthony J. House, Janet R. Griffin (2007). Effect of Change in Running Speeds on Shock Attenuation among Children. Graduate and Professional Student Association Research forum of University of Nevada, Las Vegas.

Kunal Bhanot, John A. Mercer, FACSM, Janet S. Dufek, FACSM, Julia A. Freedman, Anthony J. House, Janet R. Griffin (2006). Effect of Change in Running Speeds on Shock Attenuation among Children *27th Annual Meeting, Southwest American College of Sports Medicine*

Thesis Title:

Shock Attenuation and Impact Characteristics for Children Running at Different Stride Lengths.

Thesis Examination Committee:

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