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# Ground reaction forces for children running in different shoes

Dana Forrest
*University of Nevada Las Vegas*

# GROUND REACTION FORCES FOR CHILDREN RUNNING IN DIFFERENT SHOES

by

Dana M. Forrest

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John Mercer, Committee Chair,

Janet Dufek, Committee Member

Richard Tandy, Committee Member

Edward Neumann, Graduate Faculty Representative

Ronald Smith, Ph. D., Vice President for Research and Graduate Studies
and Dean of the Graduate College

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ABSTRACT

**Ground Reaction Forces for Children Running in Different Shoes**

by

Dana M. Forrest

Dr. John A. Mercer, Examination Committee Chair
Associate Dean, School of Allied Health Sciences
University of Nevada, Las Vegas

The purpose of this study was to determine whether certain ground reaction force parameters such as impact force (F1), second maximum force (F2), loading rate, stance time and average vertical ground reaction force (Fzavg) differ when 11-13 year old children run in a neutral shoe (Nike Air Pegasus+ 25) that is either a child or adult style.

Shoes were impact tested in an impact test instrument to determine any performance differences between the two shoes. Next, 10 healthy female subjects aged 12.03 ± 1.14 years with a height of 154.6 ± 4.90 cm and a mass of 46.18 ± 14.33 kg with a shoe size between 3.5 and 7 youth were recruited from the Las Vegas area to run 9 meters, a maximum of 40 times in the two shoes over a force platform. Loading rate was calculated using two methods: 1) rate of change in force between ground contact and F1, and 2) rate of change of force within 10 ms bin between ground contact and 50 ms. In addition to recording biomechanical parameters, after each condition subjects filled out a survey to determine personal comfort for each shoe.

Dependent variables (shoe impact data, F1, F2, Fzavg, stance time and loading rate) were analyzed using paired t-tests. Loading rate bins were analyzed using a 2 (shoe) x 5 (bin) repeated measures ANOVA. Survey data were analyzed using a paired t-test.

From the mechanical impact test analysis, it was determined that there were significant differences in force, peak acceleration and percent energy between shoes ($p<.001$). From the running test, it was determined that, loading rate was different ($p=.009$) between shoe conditions whereas F1, F2, stance time, or average vertical ground reaction force were not different between shoes ($p>.01$). It was also determined that there was no difference in loading rate between bins ($p>.05$). From the survey data, it was determined that heel cushioning was the only parameter that was different ($p=.004$) between shoes.

In order to prevent overuse injuries, it has been reported that a lower loading rate can prevent possible overuse injuries. Because a larger loading rate was observed while running in the children's shoes it is concluded that the lower loading rate for the subject wearing the adult shoe may reduce overuse injury and is the better shoe choice for girls aged 11-13 years old (Nigg, 1997).

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And to my brick walls, thank you for making me stronger everyday and providing me with the determination, tenacity and passion to succeed.

*"The brick walls are there for a reason. The brick walls are not there to keep us out; the brick walls are there to give us a chance to show how badly we want something. The brick walls are there to stop the people who don't want it badly enough."*

- Randy Pausch

# CHAPTER 1

## INTRODUCTION

Children's running shoes are often bought based on looks/style, athlete endorsement, or price; and none of these reasons may be the proper reason for buying a shoe. Instead, it seems more ideal that the running shoe is purchased using objective criteria that lead to selecting a running shoe based upon a runner's morphology and running style.

The running shoe is designed based upon a component called the last. The design of the last is based upon foot anthropometrics of people of the same gender, age and height/weight and is intended to provide the user the best fit (Cavanagh, 1980, p. 188). The fit of a shoe is an important characteristic to determine when purchasing children's shoes. For example, discomfort and possibly an injury can result if a shoe is improperly fit due to lack of appropriate movement of the foot within the shoe, or stiff and tight footwear (Staheli, 1991). Likewise, increased foot motion due to an incorrect shoe or larger size can also lead to gait changes also causing problems (Wolf, 2008). Thus, selecting a properly fit shoe is important to help reduce the chance of running injury.

To help with classifying children's feet to select shoe size, Arbeitskreis Kinderschuh developed the Wide (W), medium (M) and narrow (S) or WMS in 1974 (Walther, Herold, Sinderhauf & Morrison, 2008). At a WMS-Event in 2001, it was reported that only 46.7% of the tested children wore shoes with a proper fit (Walther et al., 2008).

It has been hypothesized that optimal foot development occurs when children are barefoot and shoes should be comfortable to protect the child (Walther et al., 2008). Between the ages of 6-10 years, the connective tissue of the subtalar joint begins to increase in stability therefore causing a decrease in the overall movement of the foot (Staheli, 1991). Around the ages of 11-14 years, children tend to adopt a running gait cycle similar to that of adults (Hausdorff, Zemany, Peng & Goldberger, 1999). It has long been hypothesized that the adult shoe should provide cushioning to minimize the risk of overuse injuries (Staheli, 1991).

Today, children at younger ages are beginning to join sports clubs and participate in sports at available facilities. Unfortunately, indoor floors and other playing surfaces are often constructed based on the weight of adults (Walther et al., 2008), suggesting that children's shoes may require additional cushioning (Staheli, 1991). The ideas of fit, anatomical development of the foot and facility surface/flooring construction lead to the question of which model shoe a child aged 11-13 years should be wearing to properly protect the foot and prevent injury during running.

## Purpose of the Study

In order to understand foot-shoe relationship for child runners, it is important to be knowledgeable of the influence of the running shoe on gait characteristics, such as ground reaction force. There is no known research on ground reaction forces exhibited for children running in children's shoes as well as running in like-sized adult shoes. Previous researchers testing adult shoes have observed differences in ground reaction forces for subjects wearing different shoes (Dufek & Bates, 1991). Given the previously discussed concerns of shoe purpose, child foot morphology and potential concerns

relative to surfaces that children perform on, the purpose of this study was to determine 1) any mechanical differences between the child and similar sized adult running shoes and 2) whether certain ground reaction force parameters such as, impact force (F1), second peak (F2), loading rate, stance time and average vertical ground reaction force, differ when 11-13 year old children run in a neutral shoe (Nike Air Pegasus+ 25) that is either a child or adult model.

## Research Question

When a child fits in the adult size footwear, this possibly provides more incorrect shoe options available for them. The last of the shoes as well as several other components may be constructed differently and provide different functional characteristics. According to NIKE.com, adding 1.5 to a youth size shoe will make it dimensionally equivalent to that of a women's shoe. Should children 11-13 years of age be wearing an adult or child shoe model? Empirical information, such as ground reaction forces generated between shoe models may lend insight into proper fit and performance of footwear for children with a long-term goal of reducing cases of lower extremity injury.

## Significance of the Study

There is little known about the exact mechanism of a running overuse injury, specifically in children. Impact forces have been reported to expose the musculoskeletal system to forces with a magnitude of 1.2-3.5 times body weight (BW; Keller, Weisberger, Ray, Hasan, Shiavi & Spengler, 1996). It has been hypothesized that the repetition of extreme ground reaction forces experienced by the body in such a brief period may be a cause of these running overuse injuries (Hreljac, 2005). This study will provide empirical data comparing the mechanical and performance properties of

children's and adult shoes. The importance of this study is to understand how shoe construction of children's shoes influences ground reaction forces and to provide insight as to whether or not the type of shoe worn could be related to running overuse injuries.

## Statistical Hypothesis

The null hypothesis for the mechanical impact tester was that there would be no difference between models in peak acceleration, force and percent energy return. The alternate hypothesis was that there would be a difference in the results for the two shoe models in peak acceleration, force and percent energy return.

The null hypothesis for running performance evaluation was that there would be no difference between the children's and adult shoe models for F1, F2, loading rate, stance time and average vertical ground reaction force. The alternate hypothesis was that there would be a difference between the children's and adult shoe models for F1, F2, loading rate (calculated as product of F1 and time to F1), stance time and average vertical ground reaction force.

Loading rate was also calculated using five 10 ms bins in which rate of change in force was calculated.  For this separate analysis, the null hypothesis for the loading rate bins was that there would be no interaction between shoe models and bin and/or no significant difference between the five loading rate bins across the two shoe models. The alternate hypothesis was that there would be an interaction between the shoe and bins and/or a significant difference between the bins across the two shoe models.

The null hypothesis for the survey results was that there would be no difference between shoe models for each measured variable listed: overall comfort, heel cushioning, fore-foot cushioning, side-to-side control, arch height, heel cup fit, heel width, fore-foot

width and shoe length. The alternate hypothesis was that there would be a significant difference in one of the measured variables of the survey for each of the variables listed: overall comfort, heel cushioning, fore-foot cushioning, side-to-side control, arch height, heel cup fit, heel width, fore-foot width and shoe length.

## Limitations/Delimitations

1) Subjects were only girls ages 11-13 years whom should have adopted adult gait patterns.

2) There were no restrictions on running experience and subjects may have had different running styles.

3) Not all subjects ran at the same speed and it was therefore more difficult to compare between subjects.

4) Only 2 shoe conditions were included and the designs and construction to that brand may have influenced results.

5) Only vertical ground reaction force characteristics were measured and changes may have been in the other components.

6) Gait patterns between each trial may have been different and not visible to the human eye nor were such possible differences evaluated.

7) Subjects were only tested at a single running speed and different results may have been observed while walking or even sprinting.

## Definition of Terms

**acceleration**: rate of change of velocity with respect to time [units: meters/second$^2$] (Hamill & Knutzen, 2009, p. 315).

**Anteroposterior axis:** the axis through the center of mass of the body running from posterior to anterior (Hamill & Knutzen, 2009, p. 18).

**Anterior superior iliac spine (ASIS):** a projection at the anterior end of the iliac crest

**average vertical ground reaction force:** Mean ground reaction vertical ground reaction force during the stance phase of running. This is a reflection of the vertical ground reaction force exerted throughout the stance phase and is subject to less intra individual variability than other measurable ground reaction forces (Munro, Miller & Fuglevand, 1987).

**avulsion fracture:** condition when a portion of the bone at the insertion of the ligament is torn away from the bone (Hamill & Knutzen, 2009, p. 43).

**contact phase:** first contact of the heel of one foot through next heel contact of the same foot (Kirtley, 2006, p. 16).

**equilibrium:** one's ability to maintain balance (Kirtley, 2006, pg. 283).

**ethylene vinyl acetate (EVA):** a closed cell foam making up the midsole of a running shoe used to absorb energy by deforming like a spring (Cavanagh, 1980, p. 46).

**force:** a push or pull that may or may not cause motion [units: Newtons] (Hamill & Knutzen, 2009, p. 368).

**gait cycle:** first contact of one foot (0%) to next contact of the same foot (100%) (Kirtley, 2006, pg. 16)

**ground reaction force:** force provided by the surface upon which one is moving in response to an applied force (Hamill & Knutzen, 2009, p. 373).

**heel counter:** component of a shoe that prevents the rearfoot from moving medially or laterally (Cavanagh, 1980, p. 43).

**impact force (F1):** greatest vertical peak value in the first 50ms of stance. F1 represents the ground reaction force associated with impact with the ground (Hamill & Knutzen, 2009, p. 398).

**inertia:** an object's resistance to change in motion (Hamill & Knutzen, 2009, p. 371).

**kinematics:** branch of mechanics that describes the spatial and temporal components of motion (Hamill & Knutzen, 2009, p. 302).

**kinetics:** branch of mechanics that studies the forces that act on a system causing motion (Hamill & Knutzen, 2009, p. 368).

**linear kinetics:** study of forces that act on a system causing translatory motion (Hamill & Knutzen, 2009, p. 368).

**loading rate:** rate of force development during impact phase of running [units: BW/s or Newtons/s] (Munro et al., 1987).

**longitudinal axis:** the axis through the center of mass of the body running from top to bottom (Hamill & Knutzen, 2009, p. 18).

**mediolateral axis:** the axis through the center of mass of the body running from right to left (Hamill & Knutzen, 2009, p. 18).

**midsole:** component of the shoe between the outsole and footbed and is typically composed of EVA, shocks, gels, springs or coils and is designed for shock absorption (Cavanagh, 1980, pg. 98, 129).

**motion:** the progressive change in position of an object over some time period (Hamill & Knutzen, 2009, p. 302).

**Newton's Law of Acceleration:** Newton's 2$^{nd}$ law of motion. Acceleration is proportional to the force impressed and inversely proportional to inertia for a given force and is made in the direction of the straight line in which force impressed [Force=mass * acceleration] (Hamill & Knutzen, 2009, p. 371).

**Newton's Law of Action-Reaction:** Newton's 3$^{rd}$ law of motion. For every action there is always an equal and opposite reaction [ $\sum F_{A\ on\ B} = -\sum F_{B\ on\ A}$] (Hamill & Knutzen, 2009, p. 372).

**Newton's Law of Inertia:** Newton's 1$^{st}$ law of motion. Every body continues in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by forces impressed on it [if $\sum F=0$ then $\Delta v=0$] (Hamill & Knutzen, 2009, p. 371)

**Osgood-Schlatter disease:** anterior knee pain due to pulling on the patella by an imbalance of strength in the quadriceps (Lau, Mahadev & Hui, 2008).

**outsole:** the bottom of the shoe that is composed of a synthetic rubber to increase traction and durability of the shoe and can be manipulated for specific activities (Cavanagh, 1980, pg. 62).

**running overuse injury:** musculoskeletal ailment attributed to running that causes a restriction of running speed, distance, duration or frequency for at least one week (Hreljac, 2004).

**pronation:** triplanar movement consisting of calcaneal eversion, abduction and dorsiflexion about the subtalar joint, the tibia moves laterally on the talus (Hamill & Knutzen, 2009, p. 226)

**second peak (F2):** vertical ground reaction force that occurs within 35 to 50% of the total stance time and is related to the active force exhibited between the shoe and the ground (Munro et al., 1987)

**Sever's Disease:** heel pain with limping caused by the Achilles' tendon on the heel bone (Lau et al., 2008)

**shin splints:** injury that occurs when the tibialis anterior pulls on its attachment site on the tibia and interosseous membrane between the tibia and fibula. (Hamill & Knutzen, 2009, p. 43)

**Sinding-Larsen-Johansson Disease:** anterior knee pain caused by an avulsion fracture of the patella (Singh & Srivastava, 2008; Lau et al., 2008)

**speed:** a scalar quantity defined as the distance traveled divided by the time it took to travel [units: meter/seconds] (Hamill & Knutzen, 2009, p. 310)

**stance time:** the time the foot is in contact with the ground during locomotion

**step:** portion of a stride from an event occurring on one leg to the same event occurring on the opposite leg. (Hamill & Knutzen, 2009, p. 320)

**stride:** interval from one event on one limb until the same event on the same limb in the following contact (Hamill & Knutzen, 2009, p. 320)

**supination:** triplanar movement consisting of calcaneal inversion, adduction and plantar flexion, the tibia moves medially on the talus. (Hamill & Knutzen, 2009, p. 226)

**swing phase:** the pendulum-like motion that occurs between toe-off to heel contact while the foot is in the air (Kirtley, 2006, pg. 16)

**translatory motion:** motion that occurs when all points on an object or body move the same distance over the same time (Hamill & Knutzen, 2009, p. 302)

**toe-off phase:** occurs at about 66% of the gait cycle separating it into stance and swing phases

**vector:** a quantity that is defined by both its magnitude and direction (Hamill & Knutzen, 2009, p. 306)

**velocity:** a vector quantity that is defined as the time rate of change of position. [units: meters/second] (Hamill & Knutzen, 2009, p. 310)

# CHAPTER 2

## REVIEW OF RELATED LITERATURE

### History of Running Shoes

Investigation of running was of great interest to many historical individuals including Aristotle, who observed motion and gait of animals and humans and Leonardo da Vinci, who chose to examine the mechanical properties of human and animal movement (Martin, 1999). These individuals were the pioneers of studying gait and anatomical properties. They led the path to analyzing the human as a mechanical body. It was discovered that like a machine, every human has its limitations and needs to be cared for appropriately to prevent damage. Footwear has been the focus of much research interest as a factor to help reduce, prevent and correct any injuries. The following will review the current footwear literature.

Footwear has been around for a long time, mainly to serve the purpose of protection of the foot. The oldest pair of running shoes, dated back to 10,000 B.C. was found in Fort Rock Cave in Oregon. The outsoles had ridges for traction and the uppers had straps to secure the shoe onto the foot (Cavanagh, 1980, p. 10). In the earlier Olympics, it has been observed in paintings that most of the athletes ran barefoot (Cavanagh, 1980, p. 15). In 1864, runners began wearing spiked shoes for track events (Cavanagh, 1980, p. 17). It was not until the first marathon in 1896 that technological running shoes began to take shape; the previously popular spiked shoes were far too dangerous for off-track courses (Cavanagh, 1980, p. 21). Although entrants wore heavy

boots with leather uppers, the rubber sole began to infiltrate designs (Cavanagh, 1980, p. 23).

In the 1930's foreign companies began to innovate the athletic shoe industry. German brothers Adolf & Rudi Dassler began developing shoes with specific design features as a means to improve running performance (Cavanagh, 1980, p. 33). Once the brothers split business associations in 1948, two popular companies were born, Adidas and Puma (Cavanagh, 1980, p. 34). Competition between them was fierce and in the 1950's both companies competed to dress more athletes at the Olympic Games (Cavanagh, 1980, p. 34). Overseas, a Japanese company, Tiger was also emerging and began importing shoes to the United States. Upon returning from a visit to Europe, track athlete Phil Knight teamed with coach Bill Bowerman at the University of Oregon. They met and collaborated with Tiger and started Blue Ribbon Sports (Cavanagh, 1980, p. 37).

In 1968, participation in recreational exercise increased in Americans and shoe prescriptions to correct gait were becoming more practical (Cavanagh, 1980, p. 38). Runners were requesting a more comfortable shoe with more cushioning. Jeff Johnson and the team at Blue Ribbon Sports developed the first midsole by applying a thin layer of rubber to the outsole (Cavanagh, 1980, p. 41). In the late 1960's running shoes were becoming more popular and the Olympics were the time for shoe companies to advertise and athletes began endorsing shoes after their victories. Former 1968 200m Gold Medalist and record holder Tommie Smith, famous for his black power silent gesture on the stand raced in the Puma "Clyde" and currently Puma still fabricates a shoe called the Puma "Clyde – Tommie Smith". Steve "Pre" Prefontaine, former University of Oregon long distance runner, was the first major track athlete to wear Nike shoes. Beneficial

performance-enhancing technology began innovating shoes from companies like Nike (formally Blue Ribbon Sports) and Adidas. This included the introduction of many technologies still seen today: heel counters, the infamous waffle outsole and a midsole created of ethylene vinyl acetate (EVA; Cavanagh, 1980, p. 45).

In the late 1970's running participation exploded and so did injuries, increasing the popularity of shoes. Running shoes were advertised everywhere and the testing and ranking processes were introduced by New Balance to establish the ultimate shoe. But as the previous technologies began getting old and overused, running shoes with air midsoles were introduced (Cavanagh, 1980, p. 47). In the 1984 Bern Grand-Prix Study a survey was given to participants of a popular 16 km race (Marti, Vader, Minder & Abelin, 1988). Of 4,358 male respondents, 45.8% had experienced running injuries over the 1-year training period (Marti et al., 1988).

Over the past 30 years, running shoes have changed and adapted in order to provide the best function, form, fit and look for the consumers. It has yet to be proven if all of these changes are beneficial to the user. Still many consumers purchase shoes due to professional athlete endorsement, not because it will benefit their health; for example, Michael Jordan's line of basketball shoes.

However, it was the tenacity and creative minds of the innovators of the early 1970's that have revolutionized running shoes forever. Although, much of the technology developed years ago will continue to be implemented in future designs, there will always be room for improvement and changes to benefit performance and more importantly prevent injuries.

Overuse Injuries

With the popularity of recreational running rising and the increased participation in children's sports the number of overuse injuries is also on the rise (Adirim & Cheng, 2003; Caspersen, Powell, Koplan, Shirley, Campbell & Sikes, 1984; DiFiori, 1999; Hawkins & Metheny, 2001; Hreljac, 2005; Jacobs & Berson, 1986; Lysholm & Wiklander, 1987; Macera, Pate, Powell, Jackson, Kenderick & Craven, 1989; Rochcongar, Pernes, Carre & Chaperon, 1995; Rolf, 1995; Walter, Hart, McIntosh & Sutton, 1989). Hreljac (2004) most succinctly defined a running overuse injury as a "musculoskeletal ailment attributed to running that causes a restriction of running speed, distance, duration or frequency for at least one week".

A stress-frequency curve has been developed by Hreljac (2004) to imitate a structure in the musculoskeletal system. Although each specific structure injures at a different rate, the theoretical curve defines an easy, straightforward way to determine overuse injuries over time. Unfortunately, it is very difficult to determine the specific time of onset or the cause of an overuse injury because symptoms can develop over a period of time and there are multiple causes of injury for different anatomical structures (Rolf, 1995). Nordin and Frankel (2001) developed an expanded explanation analyzing the two causes of an overuse injury. They observed that any type of strenuous exercise will lead to fatigued muscles. The fatigued muscles will then cause a loss of shock absorbing capacity or altered gait. These two effects of strenuous exercise will cause abnormal loading of different tissues and cause an overuse injury. However, it has been observed in previous research that during running, overuse injuries are mainly caused by

repetitive impact forces on the musculoskeletal system that fatigue the muscles (Cavanagh & Lafortune, 1980; James et al., 1978; Nigg, 1986).

Altered gait, in both children and adults, can cause an overuse injury mainly due to rear foot motion and its negative effects on pronation and supination of the foot during the contact and stance phase of running. Research has been completed to measure changes in foot kinematics during both shod and barefoot conditions and it has been observed that shoes do affect ankle coordination and foot placement (Bishop, Fiolkowski, Conrad, Brunt & Horodyski 2006; Cole, Nigg, Fick et al., 1995; James et al., 1978; Kurz & Stacoff, 2000; Stergiou, 2004). Since the focus of this protocol was to determine any ground reaction force changes between two different shod models, it is important to note that, although, the shoe sole thickness may not have an effect on joint position sense, it will affect foot placement possibly causing joints to become misaligned and cause injury (Sekizawa, Sandrey, Ingersoll & Cordova, 2001; Stacoff, Nigg, Reinschmidt, van den Bogert, Anton & Lundberg, 2000; Bishop et al., 2006).

The most common running overuse injuries in adults are stress fractures, patellar tracking problems, plantar fasciitis and Achilles tendonitis (James et al., 1978). Although children also suffer from these overuse problems, their common injuries also occur at growth plates or cartilage (Adirim & Cheng, 2003; Hawkins & Metheny, 2001). Common overuse injuries in children include Sever's disease, shin splints, Sinding-Larsen-Johansson Disease, anterior superior iliac spine (ASIS) avulsion fracture and Osgood-Schlatter disease (Adirim & Cheng, 2003; Lau, Mahadev & Hui, 2008). After reviewing 506 cases of sports-related overuse injuries, Lau et al. (2008) observed that the average overall ages for these injuries range from 9.9 years old to 12.8 years old. It was

observed by Lau et al. (2008) that the onset of puberty occurs about 2 years earlier in girls. This is directly correlated with the earlier ages of injuries in girls. However as age increases, the decreased strength and increased flexibility in girls compared to boys is an important component in helping to prevent injuries later in this adolescent phase (Lau et al., 2008). Sever's Disease is diagnosed by symptoms of heel pain and local tenderness from a pull on the Achilles' tendon (Singh & Srivastava, 2008; Lau et al., 2008). Shin splints are the cause of medial tibial stress (Hreljac, 2005). It has been observed that symptoms of Sinding-Larsen-Johansson Disease consisted of anterior knee pain caused by an avulsion fracture of the patella (Singh & Srivastava, 2008; Lau et al., 2008). Avulsion fracture of the ASIS is a tearing of the sartorius and tensor fascia lata muscles and led to hip pain in all patients and occurred in the higher age range of youth athletes, due to the final tear usually coming from a forceful pull. One might contribute onset of puberty in girls and the development of wider hips and increased q-angle to this injury, however according to the case study by Singh and Srivastava (2008) avulsion fracture of the ASIS is just as common in boys as in girls. Osgood-Schlatter Disease is anterior knee pain due to pulling on the patella by a strong quadriceps. After rest and quadriceps and hamstring strengthening, many youth athletes recover fast and successfully from this condition (Lau et al., 2008).

Although it has been observed that training errors may be to blame for over 60% of overuse injuries (Clement & Taunton, 1980; James et al., 1978, Lysholm et al., 1987), there are both extrinsic and intrinsic factors that may cause overuse injuries. Multiple studies have reviewed these factors contributing to injuries in both adult and children runners (Rolf, 1995; Singh & Srivastava, 2008). For children, these factors are similar to

those of adults, but there is an additional contribution to the percentage of injuries due to physiological growth and pressure by adults, coaches or peers (Singh & Srivastava, 2008).

Intrinsic factors are misalignments, asymmetries, previous injuries and rate of growth (Clement, Taunton, Smart & McNicol, 1981; Cook, Brinker & Mahlon, 1990; James et al., 1978). Ferber, McClay-Davis, Hamill, Pollard and McKeown (2002) observed that female subjects, who had a prior stress fracture history, exhibited a greater initial vertical impact force and loading rate. Hreljac, Marshall and Hume (2000) also observed higher initial vertical impact force in previously injured male runners.

Extrinsic factors are incorrect or rapid training, training on hard or uneven surfaces or inappropriate equipment/footwear. Tests have been done to compare midsole hardness of shoes with ground reaction forces to eliminate as much initial impact force as possible. Some researchers have reported that softer shoes actually produced a greater initial impact force if the shoe "bottoms out" (de Koning & Nigg, 1994); others have observed that softer shoes provide a lesser initial impact force. Contradicting evidence has also been reported when looking at stability of shoes. Some researchers noted greater degree of pronation in softer shoes (Clarke, Frederick & Hamill, 1983; de Wit, de Clerq & Lenoir, 1995) yet others reported lesser pronation or no difference in shoe midsole softness (Stacoff, Denoth, Kaelin et al., 1988). Most recreational runners and parents of child runners are unaware that after 250-500 miles, running shoes lose more than 40% of their shock absorbing capacity and can lead to injury (Cook et al., 1990).

Once children experience an onset of pain, it is important for them to be diagnosed by a physician because there is a greater susceptibility of injury to growth

cartilage or epiphysis plates preventing serious overuse injuries (Singh & Srivastava, 2008). It is important for runners to go through a screening process by a doctor or sports medicine professional, to look at anthropometric and biomechanical factors that may predict any occurrence of an overuse injury. With a limited number of these health care professionals, services and laboratories, one simple intervention would be identification of an appropriate running shoe.

Running shoes are considered to be protective gear and can also be used functionally as an option to correct intrinsic problems causing overuse injuries (Cavanagh & Lafortune, 1980). Repetitive loading of impact forces occurs about 500 times per kilometer for an average male adult, and even more for children due to smaller stride lengths (Cavanagh & Lafortune, 1980; Hausdorff et al., 1999). The repetitive loading causes large forces on the musculoskeletal system, about two times body weight (BW) in less than 35 ms and force will increase as fatigue sets in (Nigg, 1986). The body is required to work hard to protect and control the system from injury and to absorb the shock (Cavanagh & Lafortune, 1980; Nigg, 1986). It has been observed that a high quality, cushioned running shoe reduces the initial impact when striking the ground (Cavanagh & Lafortune, 1980; Nigg, 1986).

## Kinetics

Kinetics is the branch of mechanics that deals with the forces causing motion (Hamill and Knutzen, 2009, p. 368). When forces acting on an object are measured, we can quantify and analyze the forces to determine a practical explanation for the motion (Hamill & Knutzen, 2009, p. 368). Since running is a translatory motion, we can focus on linear kinetics to examine the forces that act on the system. There are multiple ways to

define force, a force may produce motion, stop motion, accelerate or change the direction of the object. However, it can simply be described as a push or pull between two objects that can cause either a positive or negative acceleration (Hamill & Knutzen, 2009, p. 368).

When dealing with kinetics it is important to understand Newton's Laws of Motion and both understand and apply Newton's Laws to ground reaction forces present during human gait. The following section will define Newton's Laws and the ground reaction force parameters with respect to running.

Newton's Laws include the Law of Inertia, the Law of Acceleration but more importantly to vertical ground reaction forces, the Law of Action-Reaction. Newton determined that for every action, there is always an equal and opposite reaction (Hamill & Knutzen, 2009, p. 372). It is important to understand that this pair of forces although equal in magnitude, are opposite in direction and has different effects on the object (Hamill & Knutzen, 2009, p. 372).

In terms of examining running mechanics, it is important to examine ground reaction forces versus time (Hamill & Knutzen, 2009, p. 373). Ground reaction forces are the reaction forces provided by the surface upon which one is moving. The surface pushes on the individual and the individual pushes back with an equal and opposite force. The ground reaction force will change in magnitude, direction and point of application throughout the entire time the individual is in contact with the surface. A ground reaction force is a vector that can be broken down into orthogonal components: anteroposterior, vertical, and mediolateral and can be measured using a force platform mounted in the floor. When comparing forces in running, it is important to measure forces perpendicular

to the surface in the vertical direction. It is important to look at these forces to help prevent injury and aid in the design of footwear (Hamill & Knutzen, 2009, p. 374).

Studying adult gait has been a common topic over the past 40 years. It has been reported that running produces a double-peaked ground reaction force in the vertical direction (Cavanagh & Lafortune, 1980; Munro, Miller & Fuglevand, 1987). Although ground reaction forces have previously been observed to be more variable in children, (Stolze, Kuhtz-Buschbeck, Mondwurf, Boczek-Funcke, Johnk & Deuschl, 1997) the typical vertical ground reaction force versus time graph for adults and children running are similar (Diop, Rahmani, Belli, Gautheron, Geysant & Cottalorda, 2005). The vertical ground reaction force in running depends on the individual's running pattern and classification of foot strike (Munro et al., 1987). If significant differences can be identified in the magnitude of ground reaction forces, then one can be confident that there are changes in the running patterns (Munro et al., 1987).

The F1 occurs rapidly after initial contact in running, within the first 50 milliseconds after touchdown of the heel or foot on the ground (Nigg, Denoth & Neukomm, 1981), and is sometimes referred to as the passive peak. Referring to this event as the passive peak is common because it is not under muscular control and is influenced by impact velocity, contact area between the surface and the foot, the joint angles at impact, surface stiffness and the motion of the segments (Nigg et al., 1981). Nigg et al. (1981) stated that an increased passive impact peak might be the cause of overuse injuries. This impact peak receives the most attention because it has been observed to rise to approximately 2.2 BW in rearfoot strikers and 2.7 BW in midfoot strikers running at 4.5 $m \cdot s^{-1}$ (Cavanagh & Lafortune, 1980) and it has been interpreted to

indicate the running shoe's ability to absorb shock in the heel area and may be a possible cause of overuse injuries (Bates, Osternig, Sawhill & James, 1983).

The F2 peak generally occurs within 35 to 50% of the total stance time and has been reported to increase with speed (Munro et al., 1987). Munro et al. (1987) observed male adults running at speeds from 3 $m \cdot s^{-1}$to 5 $m \cdot s^{-1}$ and reported changes in the F2 from 2.51 to 2.83 BW. It is the portion of stance where the center of gravity is the lowest. Since not all runners exhibit a F1 the F2 can be measured to compare trials. It has been reported that the F2 values are three to five times larger than the F1 (Burdett, 1982; Cole, Nigg, Fick, et al., 1995; Scott & Winter, 1990).

Loading rate is an important variable to measure since it reflects the rate of force development during the impact phase of running (Munro et al., 1987). Loading rate is closely related to the hardness of the shoe sole and the running speed (Clarke et al., 1983). Munro et al., (1987) calculated the loading rate in runners by determining the time required for the vertical force to rise from 50 N to body weight plus 50 N. They observed differences in the increase of the loading rate at different speeds (77.2 $BW \cdot s^{-1}$ at 3.0 $m \cdot s^{-1}$ to 113 $BW \cdot s^{-1}$ at 5 $m \cdot s^{-1}$). Although this method has been widely used and accepted in the adult population, no known research has been conducted examining the loading rate in children. Wright, Neptune, van den Bogert & Nigg (1998) measured loading rate by finding the mean rate of loading from contact until the F1 for all subjects. Previous researchers (Clarke, Frederick & Cooper, 1983; Dixon, 2008) have observed no significant differences when comparing F1s among shoes with different midsoles but a significantly greater loading rate in the softer shoe. Clarke et al., (1983) observed that the loading rate in the harder shoe was 22.5 ms versus 26.6 ms in the soft shoe. With a longer

loading rate, it can be deduced that some aspect of the subjects' gait must have changed (Wright et al., 1998). However, there is conflicting evidence as to whether or not there is a relationship between loading rate and overuse injuries. Gerlach, White, Burton, Dorn, Leddy and Horvath, (2005) observed that there is no difference in susceptibility of injury in previously injured female runners with a greater F1 and lower loading rates. Nigg (1997) observed that as loading rates increased, the rate of injury decreased. This can be explained by a longer time of impact, spreading the F1 over a longer period of time. This suggests that the loading rate is a more important variable to examine when measuring differences in heel cushioning in regards to vertical ground reaction force.

The average vertical ground reaction force is a reflection of the vertical ground reaction force exerted throughout the stance phase and is subject to minimal intra-individual variability (Munro et al., 1987). Typically only small differences within subject trials among variables are observed, however if these changes occur, the researcher can conclude there may have been a change in the subjects' running pattern. Munro et al., (1987) observed differences in average vertical ground reaction forces at different speeds from 1.40 BW at $3.0 m \cdot s^{-1}$ to 1.70 BW at $5.0\ m \cdot s^{-1}$. The average vertical ground reaction force is extremely beneficial in measuring since this variable can help determine any differences between trials or models. It is well known that running gait can be extremely variable when dealing with children (Stolze et al., 1997) so this is an important variable to examine more closely.

The stance phase in running was reviewed and defined by Novacheck (1998) as "the time from heel-contact to toe-off in running". It is important to measure because it can distinguish any gait changes from ground contact, in which the body decelerates and

absorbs the impact through the F2 when the center of gravity direction reverses and propels the body forward and upward into toe-off (de Wit et al., 1995). This parameter may be related to running style and leg stiffness at impact (de Wit et al., 1995).

There are many possible vertical ground reaction force parameters to measure, but only a few were found to be critical in determining differences between the constructions of running shoes (Bates, Osternig, Sawhill & Hamill, 1983). In order to study the reduction of overuse injuries, cushioning and shock absorbing capacity is an important function of running shoes to compare. The F1, the loading rate to the F1, average ground reaction force and the stance time are three vertical force parameters and one temporal that have previously been observed to produce significant differences among different conditions for cushioning that may affect ground reaction forces in order to protect the runner from any overuse injuries.

## Children's Gait

Since running is a cyclic motion it involves different repetitive sequences. It is important to note the differences between a stride and step. A stride is defined as the interval from one event on one limb until the same event on the same limb occurs in the following contact (Hamill & Knutzen, p. 320). For example, the stride length is commonly determined by examining heel contact to heel contact on the same limb (Stolze et al., 1997). A step is defined as a portion of the stride from an event occurring on one limb to the same event occurring on the opposite limb, for example, left heel strike to right heel strike. Two steps equal one stride length and also known as one complete gait cycle.

The basic kinematics of gait can be broken down into several components: 1) contact phase, when the heel or foot strikes the ground, 2) stance phase, when the center of mass begins to move anterior right before the heel begins to lift off of the ground (Hamill & Knutzen, 2009, p. 320), 3) toe-off phase in which the heel is completely off of the ground and the runner begins to push off the ground, moving forward and, 4) swing phase in which the foot is swinging forward with no contact with the ground. There is a simple way to distinguish between running and walking. In running, a shorter amount of time is spent in the stance and swing phase and in walking, one foot is always in contact with the ground (Hamill & Knutzen, 2009, p. 320).

Children's gait has been studied minimally perhaps due to great intra-individual variability of ground reaction forces among children of different ages (Takegami, 1992). Takegami (1992) reported until the age of 8 years, children have not yet developed mature kinetic patterns in the vertical direction. Running variability has been more specifically examined in children younger than 7 years of age. Children younger than 7 years of age have variable muscle recruitment patterns (Myklebust, 1990), immature stride dynamics (Hausdorff et al., 1999), immature equilibrium (Berger, Trippel & Assaiante, 1995), immature sensory organization during stance (Peterson, Christou & Rosengren, 2006), immature process of optimization during gait (Jeng, Liao & Lai, 1997) and rate of body growth (Tanner, 1962; Cameron, Tanner & Whitehouse, 1982). In children, it has been reported that the F1 is increased with speed (Diop et al., 2005). This phenomenon has also been observed in adults (White, Yack, Tucker & Hy, 1998). The F1 in children running was one variable found to be significantly different between children aged 6-8 years and 8-10 years possibly due to the characteristics of the differences in

immature gait (Diop et al., 2005). It has also been reported in children's gait that the F2 is not influenced by speed (Diop et al., 2005). This is an unexpected finding since the faster an adult runs; the greater this peak typically is (Weyand, Sternlight, Bellizzi & Wright, 2000).

It is important to note that gait of children is much more variable than that of adults and significant differences between the two populations are observed when comparing most stride characteristics. However, if the measurements are normalized to body height and leg length, the differences disappear (Hof, 1996). In the older population of children (11-13 yrs) it has been observed that children's gait is very similar to that of adults (Schepens, Willems, Cavagna & Heglund, 2001). Schepens et al. (2001) reported that the only significant difference between adults and children ages 11-12 years of age were noted when running at 4.7 $m \cdot s^{-1}$. At this abnormally fast speed for children, it has been observed that running mechanics begin to change. At all other testing speeds no difference in the running kinematics of children and adults were observed (Schepens et al., 2001).

There are a few factors that can influence the components of children's gait. Some possibilities that affect gait are changing speed, different surfaces, stride lengths and shoe conditions. Varying the speed of the individual has been observed to affect vertical ground reaction forces in adults (Keller et al., 1996). Adults that "slog" or slow jog, experienced greater vertical ground reaction forces than those who walked, resulting in a linear increase from approximately 1.2 BW to 2.5 BW (Keller et al., 1996). At faster running speeds, Weyand et al., (2000) also observed that adults apply a greater support force to the ground with increased speed. Weyand et al. (2000) reported that an individual

who runs at 11.1 $m \cdot s^{-1}$ opposed gravity with a force 1.26 times greater than an individual who runs at 6.2 $m \cdot s^{-1}$. In children ages 8-10 years of age, an increase in F1 has been observed across three different increasing velocities (Diop et al., 2005).

Changes in gait have also been observed when running over different surfaces. Stolze et al., (1997) collected data from children walking on a treadmill and overground. In the treadmill condition, it was observed that there was a reduced stride length, an increase in cadence, a decrease in overall walking cycle and also an increase in stride width compared to the overground condition. Stolze et al. (1997) concluded that the changes in children's gait might be due to lack of optical flow and lack of equilibrium from not being completely adapted to the treadmill. Not being fully adapted to a surface will affect the stride parameters so that the child can maintain balance and correct mechanics. In a more practical application, the research team of Dixon, Collop and Batt (2000) had adult subjects run over three different surfaces (asphalt, a new rubber and a synthetic sports carpet-like material) at a set speed of 3 $m \cdot s^{-1}$. Dixon et al. (2000), observed that there were no differences in joint angles across the group however they did find individual differences, either increases or decreases in ankle and knee angles among the three conditions. They also found an increased peak joint ankle angle, which indicates an increased ankle dorsiflexion, and an increase in knee flexion. Although no clear impact force differences were seen, the subtle changes observed in joint angles cause changes in running kinematics which can eventually lead to an overuse injury (Dixon et al., 2000). Any changes in temporal stride parameters are important to measure and notice because changes in ground reaction forces have been observed due to changes in stride length (SL; Mercer, Black, Branks & Hreljac, 2001). Mercer et al. (2001) observed

that as SL increased so did velocity. As aforementioned, it has been observed that as velocity increases, so do vertical ground reaction forces. As adults ran at a set SL of 2.5m, F1 increased by 0.21 $BW/m{\cdot}s^{-1}$ and at a set SL of 3.0 m, F1 increased by 0.14 $BW/m{\cdot}s^{-1}$.

Another possible cause for overuse injuries may be due to different shod conditions. Limited research has been completed on children running, however previous research has shown kinematic differences in gait patterns in children with and without shoes. Oeffinger, Brauch, Cranfill, Hisle, Wynn, Hicks and Augsburger (1999), studied the temporal stride parameters of children walking in barefoot and shod conditions. SL was observed to be 11.8 cm longer in the shod condition versus the barefoot condition. This was not due to an increased velocity, since it remained constant, but because of a decrease in cadence or the added mass on the leg of the shoe, similar to a pendulum. Oeffinger et al. (1999) also observed that events occurred later in gait when wearing shoes than in the barefoot conditions, possibly due to comfort level of the child being barefoot. Oeffinger et al. (1999) concluded that although there are visible changes in children's gait while wearing shoes, they have a small influence on the kinematics of running. Nevertheless, differences in adult gait have been observed when wearing different shoes, shoe type may also affect children's gait, more important vertical ground reaction forces (de Koning & Nigg, 1994, DeVita & Bates, 1988; Clarke et al., 1983; de Wit et al.,1995).

Owing to the lack of research done on children running, it would be reasonable to develop a database of norms for children running at different ages, speeds and under different running conditions. With this information researchers can create protocols to

examine other differences in children's running performance. We have learned that until children are at the age of 7 to 8 years, they have not yet developed mature gait patterns and cannot be considered adults. However, it is still important to remember they are smaller, still growing and should not be considered miniature adults (Rice & Waniewski, 2003). Therefore, examining any difference between the construction of children and adults shoes may help provide a better understanding of children's injuries.

# CHAPTER 3

# METHODOLOGY

## Subjects

Subjects were 10 healthy girls, aged 12.03 ± 1.14 years with a height of 154.6 ± 4.90 cm with a mass of 46.18 ± 14.33 kg. Participants were recruited from the Las Vegas area by word of mouth. Participant inclusion criteria included the requirement of having a youth shoe size between 3.5-7.0, being comfortable running for 20 minutes overground and had no current injury that interfered with running. Subjects granted assent and their parents gave written informed consent prior to youth participation (Appendix I).

## Instrumentation

### *Footwear*

Two specific running shoe models were used in this study: 1) Nike Air Pegasus +25, (Figure 1) and 2) Child Nike Air Pegasus +25 (Figure 2). The Nike Air Pegasus +25 is classified as a neutral shoe and is not designed to correct any gait or foot problems. The adult Pegasus +25 has a full-length Nike Air-sole unit and a polyurethane footbed to provide cushioning. Polyurethane is a heavy material that is dense, durable and stable. It provides maximum protection from impact. The shoes also have a lightweight phylon midsole to provide cushioning and impact protection. Phylon is composed of heated and molded ethyl vinyl acetate foam pellets or sheets and is very lightweight and responsive. The shoes also have a de-coupled and articulated crash pad to absorb the initial shock of impact. To provide lateral support and stability the adult Pegasus +25 has a midfoot

shank under the medial arch to support the foot but still allows some natural torsional rotation.


Figure 1 – Adult Nike Pegasus +25


Figure 2 – Child Nike Pegasus +25

Nike Sports Knowledge Underground, a public reference of the construction and function of specific Nike products describes the child Nike Pegasus +25 as a neutral shoe that is not to be used as an intervention for foot or gait problems. The child's shoe also

has a full-length Nike Air-Sole unit as well as a phylon midsole to provide the user a lightweight shoe with comfort and cushioning. Like the adult shoe, there is a crash pad to absorb the initial shock at impact. The shoes differ in that there is no midfoot shank in the children's shoe. Another difference stated by Nike Sports Knowledge Underground is that the children's shoe is built for durability, the upper and outsole contains stronger components in order for the shoe to last long. However since the midsoles are identical in the two shoes, any structural changes are not as noticeable in the child's shoe when it is time to replace them. Regarding the adult Pegasus+ 25, Nike Sports Knowledge Underground states that it "is a great choice if you have mildly-underpronated to mildly-overpronated gait and seek a long-wearing shoe with top-notch comfort, fit and cushioning." With regards to the children's shoe, Nike Sports Knowledge Underground states that it is "a perfect choice if you're a young runner who's looking for a lightweight, cushioned running shoe that's Nike+ ready for an enhanced running experience."

*Impact Testing System*

A mechanical impact tester (Exeter Research Inc., Brentwood, NH) interfaced to Impact Plus (version 3.0) software (Figure 3) was used to mechanically test shoes prior to human data collection. The impact tester is made up of components that measure vertical displacement, time and acceleration of an instrumented missile head during an impact. Displacement is determined by a Linear Variable Differential Transformer (LVDT) by recording changes in output voltages and peak acceleration is measured using a Kistler Accelerometer attached to the load cell and represents the greatest acceleration during impact of a shoe.

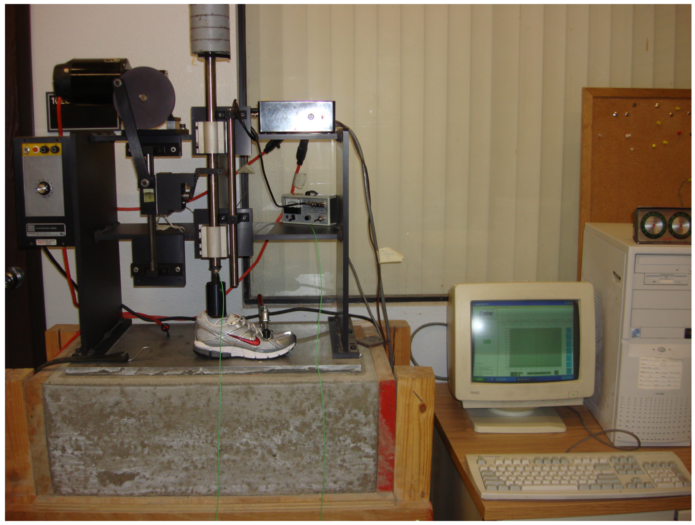

Figure 3 – Mechanical Impact tester interfaced with Impact Plus 3.0 Software and test shoe

*Force Platform*

Vertical ground reaction forces and stance time were obtained using a force platform (Kistler Model 9281C, 1000 Hz). The platform was mounted flush with the surrounding tile floor. The force platform was located halfway between the total length of a 9-meter runway.

*Timing Lights*

Running velocity was monitored with two pair of photocell timing lights (Lafayette Instruments, Model 63501 IR). The height of the timing lights was level with the shoulder of the subject and the timing lights were positioned 3.66 meters apart on both sides of the force platform. Time began when the subject ran through a beam between the first pair of timing lights and stopped when the subject ran through a beam between the second pair of timing lights.

*Survey*

A survey (Appendix I) was adapted from Mündermann, Nigg, Stefanyshyn and Humble (2002). After each description of the questioned variable, there was a line 100 millimeters long. On the left side of the line it read “not comfortable at all” (0%) and of the right side it read “most comfortable shoe imaginable” (100%). Subjects were asked to mark the line relative to their thoughts of that aspect of the shoe. Subjects were given two copies, one for each shoe, filled out immediately after wearing that model. The number of millimeters was then turned into a percentage to determine a ranking of the shoes.

## Procedure

*Shoe Impact Testing*

Material testing using the Impact Testing System (3000 Hz) occurred prior to subject data collection. The two shoe models, size 4.5 youth and 6 women, were rear-foot tested for midsole hardness prior to human testing following a modified American Standard for Testing Materials (ASTM) Standard Test Method for Shock Attenuating Properties of Material Systems for Athletic Footwear procedure (ASTM F1614-99). The load cell mass was 2.8 kg (with an added 5.7 kg to adhere to ASTM standards of 8.5 kg) and was dropped from a height of 50 millimeters twenty-five times to pre-load the material and then ten times (vs. 5 per ASTM standard) to test and record data.

*Running Procedures*

Once recruited for the study, subjects set up a time to come into the laboratory for data collection. Prior to testing, the following instructions were given, “You will be participating in a study to evaluate the effectiveness of new shoes. In this study you will be asked to run across the floor stepping on a blue marker. You will do this wearing each

of two different pair of shoes. Both shoes are standard running shoes that you can purchase in stores. After you have tried both shoes, you will be asked to fill out a survey with a few questions."

The subjects' height and weight were next measured and recorded. Subjects were unaware of the two shoe models and the order of shoes was self-selected by the subject. Eight out of ten subjects selected the children's shoe first.

The subjects ran six practice trials over 9 meters and were instructed to step on a blue marker on the force platform (Figure 4). During the first three trials the location of the step prior to stepping on the force platform was estimated by eye an averaged. A blue marker was placed on this location in order to assist subjects with striking the force platform in a consistent pattern. For the last three practice trials subjects ran while hitting both blue markers on the floor at a comfortable pace which was calculated by dividing the displacement of the subject (3.66 meters) over time and then averaged to determine their "self-selected" speed. Velocity was recorded for each of these trials. The test velocity was determined by using the velocity of these trials.

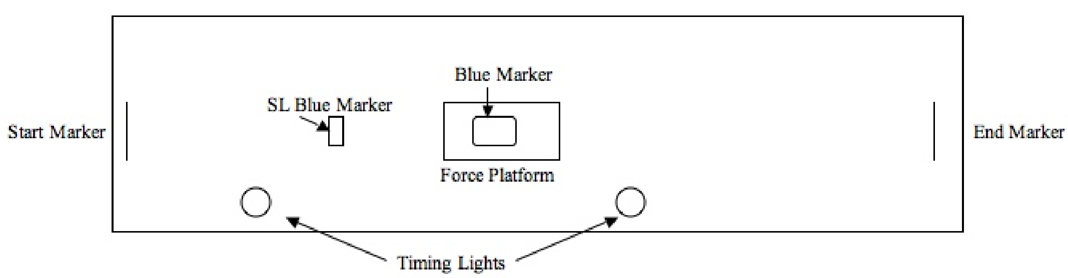


Figure 4. Representation of the 9 meter runway and placement of blue markers and timing lights.

Once comfortable with the protocol, the data collection began. For the rest of the trials, the subjects' speed was monitored and required to remain at a speed of ±10% of the set "self-selected" speed. A maximum of 20 trials were performed in order to obtain 10 successful trials. A bad trial consisted of one or more of the following: 1) velocity out of the ±10% acceptance window, 2) subject missed either blue marker, 3) subject altered gait to hit blue markers (e.g. stutter stepped, skipped, hopped or looked down). After 10 successful trials were collected, the subject filled out a survey (Appendix I) based on that shoe model and then repeated the protocol in the other test shoe, concluding with the survey for the second shoe model. Once completing the final survey, the child was given a t-shirt, thanked for completing the experiment and dismissed.

<u>Data Reduction</u>

*Impact Tester*

Peak acceleration, force and percent energy return during impact were identified in order to compare mechanical characteristics of the midsole hardness of the running shoes. The Impact Plus 3.0 software calculated all parameters per manual specifications. Specifically, percent energy return was determined by dividing the missile rebound height over the missile drop height and then multiplying by 100. The peak force, also calculated by the Impact Plus 3.0 software was obtained by deriving acceleration from position data and then using the equation $\Sigma F=ma$. Velocity was calculated using the first central difference method where $v_i= (x_{i+1} - x_{i-1})/(2*\Delta t)$. Velocity was then used to calculate acceleration, $a_i=(v_{i+1} - v_{i-1})/(2*\Delta t)$. The first 5 trials of the 10 recorded trials that had percent energy return magnitude were greater than 1 were returned for analysis. Generally percent energy return magnitudes are around 35-40%. In some cases, it was

observed that percentage of energy return was less than 1. Mathematically, this means that when the load cell dropped onto the shoe, it stayed there and did not rebound up. In practical testing, this did not actually happen and therefore these trials were not considered for analysis.

*Force Platform*

Force platform data collected using Bioware were exported into a custom MatLab program (Appendix II) and ground reaction force data during stance were extracted for analysis. Ground contact was determined to be the point at which the vertical force was greater than 20N. Force data were reduced to yield the following dependent variables: F1, F2, loading rate, average vertical ground reaction force (Fz average) and stance time. The F1 was determined as the first peak that occurred within 50ms after ground contact. The F2 was measured as the second peak that occurred about 50% of midstance. The average vertical ground reaction force was determined by calculating the average force during contact. Stance time was calculated as the time the subject was in contact with the ground, from ground contact to toe-off. Loading rate was calculated as the magnitude of F1 over the time to F1. If there was no F1, the loading rate was 0 and the time to F1 was replaced as the total stance time; these trials were not included in analysis of F1 or stance time. To conduct a follow up analysis of loading rate, loading rate was calculated for 10 ms bins up to 50 ms after contact or until F1 was observed. The loading rate for each bin was calculated as the slope of the F1 versus time plot within each bin.

## Statistical Analysis

Shoe impact test data were compared between shoes using a paired t-test for ($\alpha$=.017). The dependent variables from the running test (F1, F2, Fzavg, stance time,

loading rate) were compared between shoes using a paired t-test. Alpha level was adjusted using a Bonferroni correction ($\alpha$=.01). Loading rate was also compared between bins and shoes using a 2 (shoe) x 5 (bin) repeated measures analysis of variance ($\alpha$=.05). A paired t-test ($\alpha$= .005) was used to measure significance for the survey results.

## CHAPTER 4

## RESULTS

Shoe impact test results identified significant differences in peak acceleration, force and percent energy return between the two shoes (Table 1). With alpha level set at $\alpha$=.017, peak acceleration (t=2.31; p<.001), force (t=2.31; p<.001) and percent energy return (t=2.31; p<.001) were greater in the children's shoes.

Table 1 – Average and Standard Deviation Results for Impact Tester

| | Children's Shoe | Adult's Shoe |
|---|---|---|
| Peak Acceleration (g) | 24.24 ± 0.004 | 22.64 ± 0.390 * |
| Force (N) | 2020.77 ± 0.239 | 1886.69 ± 32.582 * |
| Energy Return (%) | 47.64 ± 0.385 | 40.05 ± 2.190 * |

* Significantly different between shoe models (p<.017)

Means and standard deviations for each ground reaction force dependent variable are presented in Table 2. F1 (t=2.52; p=.033), F2 (t=1.48; p=.174), average vertical ground reaction force (t=1.95; p=.840) and stance time (t=-1.62; p=.139) were not different between shoes. However, loading rate was significantly different between running shoes (t=3.29; p=.009).

Table 2 - Ground Reaction Force Characteristics (Mean ± Standard Deviations)

| | Children's Shoe | Adult's Shoe |
|---|---|---|
| F1 (BW) | 2.46 ± 0.76 | 2.09 ± 0.83 |
| F2 (BW) | 3.42 ± 1.16 | 3.37 ± 1.11 |
| Fz Average (BW) | 2.03 ± 0.64 | 1.97 ± 0.58 |
| Stance time (s) | 0.22 ± 0.03 | 0.23 ± 0.03 |
| Loading Rate (BW/s) | 105.85 ± 52.31 | 79.78 ± 38.77 * |

* Significantly different between shoe models (p<.01)

It was observed that subjects exhibited an F1 value only 86.5% of the time. Loading rate was then separated into five temporal bins. From this second analysis, it was determined that loading rate was not influenced by the interaction of shoe and bin (Figure 5, p=.181). Furthermore, loading rate was not different between bins (p=.068) or between shoes (p=.292).

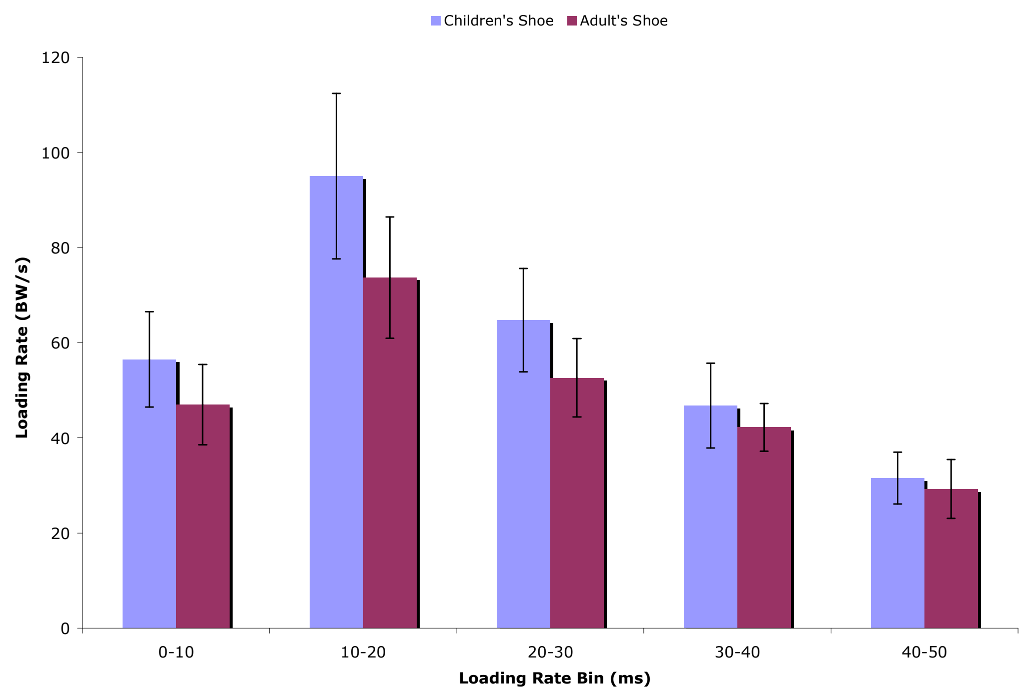


Figure 5: Average Loading Rate for each 10ms bin and the standard error.

From the analysis of survey data, ($\alpha$=.005) it was determined that only the perception of heel cushioning was different between shoes with subjects indication that they were more comfortable in the adult shoe vs. children's shoe ($p$=.004). There were no differences in any of the remaining responses ($p$>.005) (Table 3).

Table 3 - Average and Standard Deviation (%) Results for Survey Responses

| | Children's Shoe | Adult's Shoe |
|---|---|---|
| Overall Comfort | 66.63 ± 27.05 | 85.00 ± 16.63 |
| Heel Cushioning | 62.50 ± 22.28 | 87.90 ± 10.79 * |
| Fore-Foot Cushioning | 63.20 ± 32.69 | 76.90 ± 25.57 |
| Side-to-Side Control | 53.70 ± 33.50 | 86.20 ± 21.04 |
| Arch Height | 66.10 ± 33.01 | 82.30 ± 33.51 |
| Heel Cup Fit | 65.40 ± 33.51 | 87.70 ± 15.06 |
| Heel Width | 64.90 ± 26.02 | 85.10 ± 17.17 |
| Fore-Foot Width | 69.50 ± 33.64 | 87.30 ± 18.12 |
| Shoe Length | 76.00 ± 25.65 | 88.10 ± 10.79 |

* Significantly different between shoe models ($p$<.005)

# CHAPTER 5

# DISCUSSION

The purpose of this study was to determine 1) any mechanical differences between the child and similar sized adult running shoes and 2) whether certain ground reaction force differ when 11-13 year old children run in a neutral shoe (Nike Air Pegasus+ 25) that is either a child or adult model. To accomplish this purpose, children ran at a self-selected speed in each pair of shoes. Prior to testing children running, it was determined that the two shoes were visually and structurally different. It can be reported that the two shoe models, the adult and the children shoe, are structurally different Specifically, shoe performance difference on the current study's impact testing results suggests that adult shoes are the better shoes for absorbing impact energy, reducing shock absorption and a lesser force at impact. It is also important to note that both shoes were built for different populations, particularly adults and children and it is not known if the ASTM shoe test parameters are appropriate for testing children shoes. For example, the ASTM shoe test parameters are set as per a typical runner mass. Nevertheless, since the impact test results were different between shoes, it was reasonable to expect a difference in ground reaction force impact variables between shoes. Interestingly, none of the ground reaction force variables measured were different between shoes except for loading rate. In this case, loading rate was 25% greater when children ran in the children shoe vs. the adult shoe. Although the observed loading rates were different, it is unclear whether one is more dangerous than the other. It might be that both loading rates are

within a safe region. Furthermore, there is no known research that has empirically determined that shoes reduce the chance of having an overuse injury.

There is an emphasis on understanding loading rate during running since it has been hypothesized that the frequency of overuse injury to runners is lower when loading rate is lower in magnitude (Bahlsen, 1989; Nigg, 1997). In the current study, it was determined that loading rate was different between the two shoes even though F1 was not different between shoes. Other researchers have observed a change in loading rate and no difference in F1 (Clarke, Frederick & Cooper, 1983; Dixon, 2008). In adults, loading rate has been observed to be 77.4 ± 19 BW/s when running at 3.25 ± 0.62 $m \cdot s^{-1}$ (Munro et al., 1987). In the current study, a higher loading rate (105.85 ± 52.31 BW/s) was observed for the children's shoe model but a similar loading rate (79.78 ± 38.77 BW/s) was observed in the adult shoe model when running at an average speed of 3.21 ± 0.56 $m \cdot s^{-1}$. It is not clear why there is a difference in loading rate between studies for the children's shoe but not the adult shoe.

A possible explanation for a difference in loading rate between the results from the children's shoe model in this study and Munro et al's (1987) data is the method of calculating the loading rate. Munro et al. (1987) calculated loading rate from the time the ground reaction force curve exceeded 50N until it reached 50N greater than 1BW. In the present study, loading rate was calculated by dividing F1 over time of occurrence of F1. It is interesting to note that although the calculation to define loading rate is different between the current study and Munro et al., (1987), the results for an adult running in an adult shoe in Munro et al., (1987) exhibited loading rates of 77.4 ± 19 BW/s which is very similar to the results for children running in an adult shoe 79.78 ± 38.77 BW/s. This

similarity in results for the adult shoes help to verify that the data for children in the adult shoe are valid and further suggest a functional difference between the two shoe models. However, it is not clear if the loading rate would be different due to method of calculation if adults ran in the adult shoes.

Mathematically, loading rate will change when 1) F1 increases for a given time, 2) time to F1 increases for a given F1 or 3) both F1 and time to F1 change slightly. In the present study neither F1 nor the time to F1 were significantly different between shoes. By using the calculation for loading rate, change in force over change in time, either the magnitude of F1 or time to F1 would need to change in order for a significant difference in loading rate to be identified. Typically in adults the F1, has been observed before the 50 ms time mark (Nigg, Denouth & Neukomm, 1981). While there is no research to our knowledge that reports the time to F1 for children as a percentage of stance, the F1 occurred at 28.0 ± 0.01ms (12% of stance) and 30 ± 0.01ms (13% of stance) respectively in the children's and adult shoe, suggesting no difference between the time of occurrence of F1 between shoes. Although F1 did not occur in every trial (only 86.5% of the time; Figure 6; Table 4), it was observed that there was no significant difference between magnitudes of F1 between shoes. It is reasonable to hypothesize that both variables fluctuated slightly causing a change in loading rate, but neither changed enough to identify significant differences.

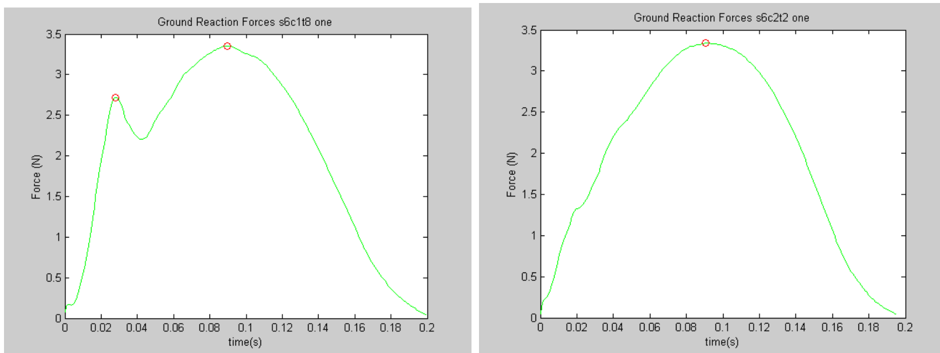


Figure 6 – Representative Vertical GRF for one subject that had trials with and without a visible F1

Table 4 – Percent of trials containing F1 by-subject

| Subject # | Children's Shoe | Adult's Shoe |
|---|---|---|
| 1 | 80% | 50% |
| 2 | 80% | 90% |
| 3 | 90% | 90% |
| 4 | 100% | 90% |
| 5 | 100% | 80% |
| 6 | 90% | 100% |
| 7 | 80% | 50% |
| 8 | 90% | 90% |
| 9 | 90% | 100% |
| 10 | 100% | 90% |
| | Mean: 90% | 83% |
| | SD: 8.16% | 18.29% |

It is not clear if loading rate was different between shoes due simply to the differences in shoe structure or if the children changed their gait pattern. Given that the adult shoes absorbed more impact energy than the children shoe in the impact test, it seems reasonable that loading rate would be lower in the adult vs. child shoe. A shoe that absorbs more impact energy does so by increasing the time for missile head to reach 0 and represents a shoe that absorbs more of the impact force.

Loading rate may also have been different between shoes because running gait changed. For example, if the skeletal alignment was different at impact between shoes, joint loading could be different and influence loading rate. A change in skeletal alignment can occur with different footstrike patterns, for example. Since kinematics were not measured in this study, this idea cannot be directly addressed. However, stance time was examined and it was determined that there was no change in stance time between shoes. This may be an indication that running gait did not change between shoes. However, a confounding factor is that running speed was monitored over a 3.66 m distance and it is not known if subjects made subtle changes in running speed within this distance. If speed did change within the 3.66 m, that could influence the results. Future research is needed to determine if subtle fluctuations of running speed influenced the outcome of the study. A kinematic analysis could detect more subtle running velocity changes.

In the current study, F1 was not significantly different between shoes, 2.46 ± 0.76 BW in the children's shoe and 2.09 ± 0.83 BW in the adult's shoe while running 3.25 ± 0.62 $m \cdot s^{-1}$ in the children's shoe and 3.21 ± 0.56 $m \cdot s^{-1}$ in the adult's shoe. These magnitudes are similar to previous research studying F1 in adult runners (e.g., Cavanagh & Lafortune, 1980; Munro et al., 1987). For example Munro et al. (1987) observed an F1 of 1.69 BW at a velocity of 3.25 $m \cdot s^{-1}$. Cavanagh & Lafortune (1980) observed F1 values of 2.20 BW in rearfoot strikers running at 4.50 $m \cdot s^{-1}$. Miller (1990) also reported F1 magnitudes between 2-3 BW in adults running at velocities between 3 and 5 $m \cdot s^{-1}$. In the present study, children ran at an average speed of 3.25 ± 0.62 $m \cdot s^{-1}$ in the children's shoe and 3.21 ± 0.56 $m \cdot s^{-1}$ in the adult's shoe so the magnitudes are reasonable relative to the

speed. Further research is needed to determine if F1 is similar or different between children and adults when running speed is accounted for.

F2 in the current study seems to have greater magnitudes than in previous research on adults running (Bates & James, 1983; Cavanagh & Lafortune, 1980; Clarke et al, 1983b; Munro et al., 1987). In the children's shoe, ground reaction forces were 3.42 ± 1.16 BW and 3.37 ± 1.11 BW in the adult's shoe, with no significant difference in F2 between shoes. In comparison, Munro et al. (1987) reported F2 magnitudes of 2.56 ± 0.17 BW in adult subjects running at 3.25 $m{\cdot}s^{-1}$. Other research on adults used a protocol with much higher velocities (3.60 $m{\cdot}s^{-1}$ - 4.50 $m{\cdot}s^{-1}$; Bates & James, 1983; Cavanagh & Lafortune, 1980; Clarke et al., 1983b). Given that the children in the present study ran slower than the adults in these studies, it is not clear why F2 would be greater for the children vs. adults.

The larger magnitude of F2 in this study may be due to a larger penetration of the heel in the midsole at impact. Like Clarke et al., (1983b) higher F2 magnitudes occur in the shoe with the higher F1 values. The larger penetration into the heel provides a lower position, which theoretically would form a larger plantar flexor torque and produce more ground reaction force for a larger propulsion force (Clarke et al., 1983b) thus influencing F2. However, F1 was similar between shoe conditions in the present study and therefore it is not known whether or not impact penetration was different between conditions.

The average vertical ground reaction force was not different when subjects ran in the children and adults shoe (p=.084). Average vertical ground reaction forces in the children's shoe were 2.03 ± 0.64 BW and 1.97 ± 0.58 BW in the adult's shoe. Using a similar velocity of 3.25 $m{\cdot}s^{-1}$, Munro et al. (1987) observed an average vertical ground

reaction force in adults of 1.44 ± 0.08 BW. A larger average vertical ground reaction force is in line with the observation that F1 and F2 appear to be greater in children vs. adults. Since average vertical ground reaction force gives a sense of running pattern and vertical acceleration of the total body center of gravity and the discrete forces did not differ, it seems that running style may not have changed between shoes, yet the child running style may be discretely different from an adult running style.

Another important finding was there were no observed differences in stance time between shoes. Stance time was measured as a way to detect changes in the children's gait between shoes. This parameter may be related to running style and leg stiffness at impact (DeWit et al., 1995). Parameters like leg stiffness and stride length are good descriptors of running style, since stance time was not different between shoes, it seems that running style did not change between trials and conditions. In the children's shoe, stance time was 0.22 ± 0.03 s and in the adult's shoe 0.23 ± 0.03 s. Munro et al. (1987) observed a stance time of 0.26 ± 0.18 s for adults running at a similar velocity of 3.25 $m \cdot s^{-1}$. DeWit (2000) measured the stance time in male adults and found similar results. Subjects ran at 3.50 $m \cdot s^{-1}$ and had a stance time on average of 0.25 ± 0.01 s. The difference in the stance time results between Munro et al., (1987), DeWit (2000) and the present study may be related to the age of the subjects, adults vs. children, or may be due to the method of determining stance time. Munro et al. (1987) calculated the stance time in which the vertical ground reaction force exceeded 16 N whereas in the present study, 20 N was used as the minimum ground reaction force to identify stance time. Since a greater force criterion was used in the present study, and subjects had a lower mass, this

alone may explain a shorter stance time. Running style of the children in the present study and that of the adults in previous research may be different as well.

It was important in this experiment that the subjects ran with a comfortable, natural, unaltered gait and strike the force platform similarly unencumbered. From a qualitative perspective, it is often hard to know what the right way to say or give instructions to subjects to have them run using a comfortable, natural gait. Working with children complicates this and it is not known how instructions to children subjects influenced their choice of running style or speed or if fatigue during the protocol were factors.

Although subjects were compared with themselves, they all ran at different self-selected speeds (Table 5). It is not known whether or not different speeds for each subject makes it more difficult to determine any commonality between the shoe models. Munro et al. (1987) reported that running velocity affects ground reaction forces. It has also been observed that for children ages 11-13 years, running at speeds of 4.70 $m \cdot s^{-1}$ or greater affects kinematics of gait (Schepens et al., 2001). All of the current subjects ran at an average speed of $3.25 \pm 0.62$ $m \cdot s^{-1}$ in the children's shoe and $3.21 \pm 0.56$ $m \cdot s^{-1}$ in the adult's shoe and these speeds were not different between shoes ($p=.264$). Ultimately, ground reaction forces should be further researched more closely at different speeds.

Table 5 – Mean speed ± standard deviation for the children's and adult's shoe models by-subject.

| Subject # | Children's Shoe | Adult's Shoe |
|---|---|---|
| 1 | 2.87 ± 0.19 $m \cdot s^{-1}$ | 2.77 ± 0.06 $m \cdot s^{-1}$ |
| 2 | 2.84 ± 0.14 $m \cdot s^{-1}$ | 2.96 ± 0.08 $m \cdot s^{-1}$ |
| 3 | 4.08 ± 0.10 $m \cdot s^{-1}$ | 3.81 ± 0.18 $m \cdot s^{-1}$ |
| 4 | 4.18 ± 0.24 $m \cdot s^{-1}$ | 4.12 ± 0.24 $m \cdot s^{-1}$ |
| 5 | 3.82 ± 0.12 $m \cdot s^{-1}$ | 3.78 ± 0.22 $m \cdot s^{-1}$ |
| 6 | 3.69 ± 0.11 $m \cdot s^{-1}$ | 3.54 ± 0.19 $m \cdot s^{-1}$ |
| 7 | 2.61 ± 0.08 $m \cdot s^{-1}$ | 2.72 ± 0.09 $m \cdot s^{-1}$ |
| 8 | 2.61 ± 0.06 $m \cdot s^{-1}$ | 2.54 ± 0.12 $m \cdot s^{-1}$ |
| 9 | 3.12 ± 0.06 $m \cdot s^{-1}$ | 3.08 ± 0.12 $m \cdot s^{-1}$ |
| 10 | 2.71 ± 0.13 $m \cdot s^{-1}$ | 2.75 ± 0.15 $m \cdot s^{-1}$ |
| | Mean: 3.25 $m \cdot s^{-1}$ | 3.21 $m \cdot s^{-1}$ |
| | SD: 0.62 $m \cdot s^{-1}$ | 0.56 $m \cdot s^{-1}$ |

It is interesting to note that the only significant difference in the survey results was when heel cushioning was measured for personal comfort. The fact that the adult shoe was rated to have more comfortable cushioning seems to suggest that if children were offered this condition, it would be preferred. After speaking with the subjects, some subjects noticed the adult shoe being more comfortable, especially the cushioning. One parent even noticed her daughter's posture immediately improve. Although this is anecdotal information, the comfort of the subject is also important and is a factor that should be further explored by testing more shoe options.

## Recommendations for Future Research

Future research should examine loading rate more closely by measuring number of loading cycles over time and rest periods to further determine loading rates as a cause of overuse injuries. It is important that any future research also examine kinematics of children running in the two different shoe models to observe any skeletal misalignment or changes in gait unnoticeable in vertical ground reaction forces in the two shoes.

## Conclusion

It has long been thought that it is important to select an appropriate running shoe to minimize the risk of overuse injury. In order to prevent overuse injuries, it has been reported that a lower loading rate can prevent possible overuse injuries. Because a larger loading rate was observed while running in the children's shoes it is concluded that the lower loading rate for the subject wearing the adult shoe may reduce overuse injury and is the better shoe choice for girls aged 11-13 years old.

APPENDIX I

IRB FORMS

SURVEY

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

UNLV IRB
Approved NOV 12 2008
Expires NOV 11 2009

# Biomedical IRB – Full Board Review
# Approval Notice

***NOTICE TO ALL RESEARCHERS:***
*Please be aware that a protocol violation (e.g., failure to submit a modification for any change) of an IRB approved protocol may result in mandatory remedial education, additional audits, re-consenting subjects, researcher probation suspension of any research protocol at issue, suspension of additional existing research protocols, invalidation of all research conducted under the research protocol at issue, and further appropriate consequences as determined by the IRB and the Institutional Officer.*

**DATE:** December 12, 2008

**TO:** **Dr. John Mercer**, Kinesiology

**FROM:** Office for the Protection of Research Subjects

**RE:** Notification of IRB Action
Protocol Title: **Ground Reaction Forces for Children Running in Different Shoes**
Protocol #: 0810-2888

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This memorandum is notification that the project referenced above has been reviewed by the UNLV Biomedical Institutional Review Board (IRB) as indicated in Federal regulatory statutes 45CFR46. The protocol has been reviewed and approved.

The protocol is approved for a period of one year from the date of IRB approval. The expiration date of this protocol is November 11, 2009. Work on the project may begin as soon as you receive written notification from the Office for the Protection of Research Subjects (OPRS).

**PLEASE NOTE:**
Attached to this approval notice is the **official Informed Consent/Assent (IC/IA) Form** for this study. The IC/IA contains an official approval stamp. Only copies of this official IC/IA form may be used when obtaining consent. Please keep the original for your records.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through OPRS. No changes may be made to the existing protocol until modifications have been approved by the IRB.

Should the use of human subjects described in this protocol continue beyond November 11, 2009, it would be necessary to submit a **Continuing Review Request Form** *60 days* before the expiration date.

If you have questions or require any assistance, please contact the Office for the Protection of Research Subjects at OPRSHumanSubjects@unlv.edu or call 895-2794.

Office for the Protection of Research Subjects
4505 Maryland Parkway • Box 451047 • Las Vegas, Nevada 89154-1047

RECEIVED
FEB 23 2009

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

UNLV IRB
Approved
FEB 19 2009
Expires
NOV 11 2009

Department of Kinesiology

ASSENT TO PARTICIPATE IN RESEARCH

## Ground Reaction Forces for Children Running in Different Shoes

1. My name is Dana Forrest; I am a graduate student in the 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 a part of this study, you must be physically active, you must not have any injury that makes it hard for you to run, and you must be between 11 and 13 years old.

3. During the test, we will ask you to run several times in the lab. Each run will only be a short distance of about 20 yards. We will give you specific running shoes to run in.

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. Next, we will ask you to answer some questions about the comfort level of the shoes and why you like or don't like certain shoes.

6. By being part of this study we hope that you learn more about how important running shoes are for children.

7. 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.

8. If you don't want to be in this study, you don't have to participate.

9. 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 or Dr. Mercer at 895-3419 or ask me next time or have your parents call me.

10. Signing your name at the bottom means that you want 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

RECEIVED

FEB 23 2009

UNLV

UNIVERSITY OF NEVADA LAS VEGAS

UNLV IRB Approved FEB 19 2009 Expires NOV 11 2009

# PARENT PERMISSION FORM

**Department of Kinesiology**

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**TITLE OF STUDY: Ground Reaction Forces for Children Running in Different Shoes**

**INVESTIGATOR(S): John Mercer, Ph.D., Janet Dufek, Ph.D., Dana Forrest, Philana-Lee Gouws**

**CONTACT & PHONE NUMBER: John Mercer, Ph.D. or Dana Forrest; 895-3419**

---

**Purpose of the Study**

Your child is invited to participate in a research study. The purpose of this study is to better understand how important running shoes are for children.

**Participants**

Your child is being asked to participate in the study because he/she is physically active, free from injury and is between the ages of 11 and 13 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 at any time. Your child must not have any injury that would make it hard for him/her to run.

**Procedures**

If your child participates in the study, we will first measure his/her height, weight and shoe size.

We will then fit your child with two different pairs of shoes. One pair of shoes are made specifically for children, the other is made for adults – but they are the same size.

Once instrumented your child will be asked to run overground. He/she will run about 20 yards over two force platforms. The force platforms are like bathroom scales and will measure how hard your child pushes on the ground while running. We will try to collect 10 trials, where a 'good' trial is one where the correct speed was achieved and the foot struck the force platform. This will then be repeated while wearing the other pair of shoes.

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 will be provided to the child if he/she wants to have a drink.

Your child will also be asked to answer some questions to rate the comfort and feel of the shoes provided as well as some questions to learn why they like to purchase specific shoes.

Participant Initials _____

1 of 3

**TITLE OF STUDY: Ground Reaction Forces for Children Running in Different Shoes**

**INVESTIGATOR(S): John Mercer, Ph.D., Janet Dufek, Ph.D., Dana Forrest, Philana-Lee Gouws**

**CONTACT PHONE NUMBER: John Mercer, Ph.D. or Dana Forrest; 895-3419**

---

During all tests, your child will have time to rest in between trials. It will take about 1 hour 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 running characteristics of children his/her age.

**Risks of Participation**

There are risks involved in all research studies. This study may include only minimal risks. As in all running activities 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 experience after a physical education class. We can minimize any muscle soreness by giving him/her time to warm up and give ample rest in between trials.

**Cost /Compensation**

There will not be financial cost to you to participate in this study, a daily parking permit will be provided to you to be used the day of data collection. The study will take about 1 hour on the day of your scheduled time. You will not be compensated for your time. However we will provide your child a t-shirt. Your child can keep the t-shirt regardless of completing the study. *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 or your child have any questions or concerns about the study, you may contact John Mercer, Ph.D. or Dana Forrest at 895-3419. 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. Your child may refuse to participate in this study or in any part of this study. Your child may withdraw at any time without prejudice to your relations with the university. You and your child are encouraged to ask questions about this study at the beginning or any time during the research study.

**Confidentiality**

All information gathered in this study will be kept completely confidential. No reference will be made in written or oral materials that could link your child to this study. All records will be stored in a

Participant Initials _____

RECEIVED

FEB 23 2009

UNLV IRB Approved FEB 19 2009 Expires NOV 11 2009

**TITLE OF STUDY: Ground Reaction Forces for Children Running in Different Shoes**

**INVESTIGATOR(S): John Mercer, Ph.D., Janet Dufek, Ph.D., Dana Forrest, Philana-Lee Gouws**

**CONTACT PHONE NUMBER: John Mercer, Ph.D. or Dana Forrest; 895-3419**

locked facility at UNLV for 3 years after completion of the study and identifiable information destroyed thereafter.

**Participant 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

______________________________
Child's Name (Please print)

______________________________
Parent Name (Please Print)

______________________________
Date

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

Participant Initials _____

**Survey**

Subject #: ________
Shoe Condition #: ________

**overall comfort** |-----------------------------------------------------------------------------------|
not comfortable at all — most comfortable shoe imaginable

*[overall impression of the shoe]*

**heel cushioning** |-----------------------------------------------------------------------------------|
not comfortable at all — most comfortable shoe imaginable

*[softness/hardness of the heel part]*

**fore-foot cushioning** |-----------------------------------------------------------------------------------|
not comfortable at all — most comfortable shoe imaginable

*[softness/hardness of the front part]*

**side-to-side control** |-----------------------------------------------------------------------------------|
not comfortable at all — most comfortable shoe imaginable

*[position of the foot controlled by the shoe]*

**arch height** |-----------------------------------------------------------------------------------|
not comfortable at all — most comfortable shoe imaginable

*[height of shoe under the arch of the foot]*

**heel cup fit** |-----------------------------------------------------------------------------------|
not comfortable at all — most comfortable shoe imaginable

*[fit of the heel in the back of the insole]*

**heel width** |-----------------------------------------------------------------------------------|
not comfortable at all — most comfortable shoe imaginable

*[width of the shoe in the back of the shoe where heel fits]*

**fore-foot width** |-----------------------------------------------------------------------------------|
not comfortable at all — most comfortable shoe imaginable

*[width of the shoe in the front part]*

**shoe length** |-----------------------------------------------------------------------------------|
not comfortable at all — most comfortable shoe imaginable

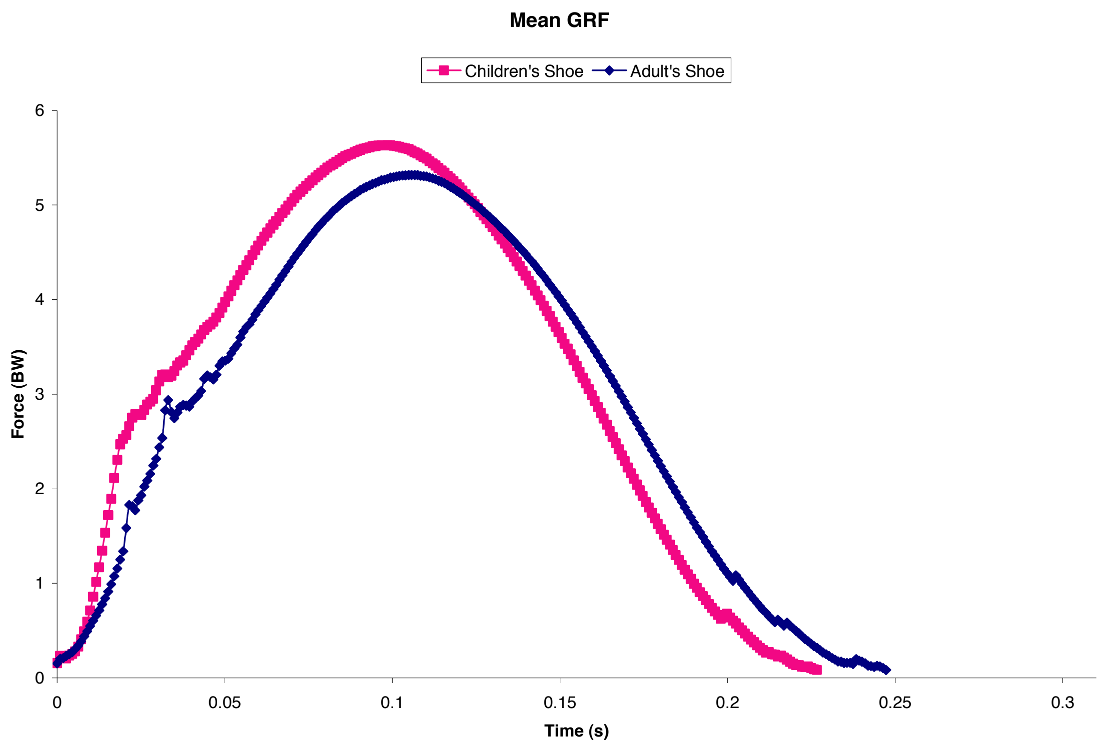
*[length of the shoe]*

(Adapted from, Mündermann, Nigg, Stefanyshyn & Humble, 2002)

# APPENDIX II

# INDIVIDUAL SUBJECT DATA

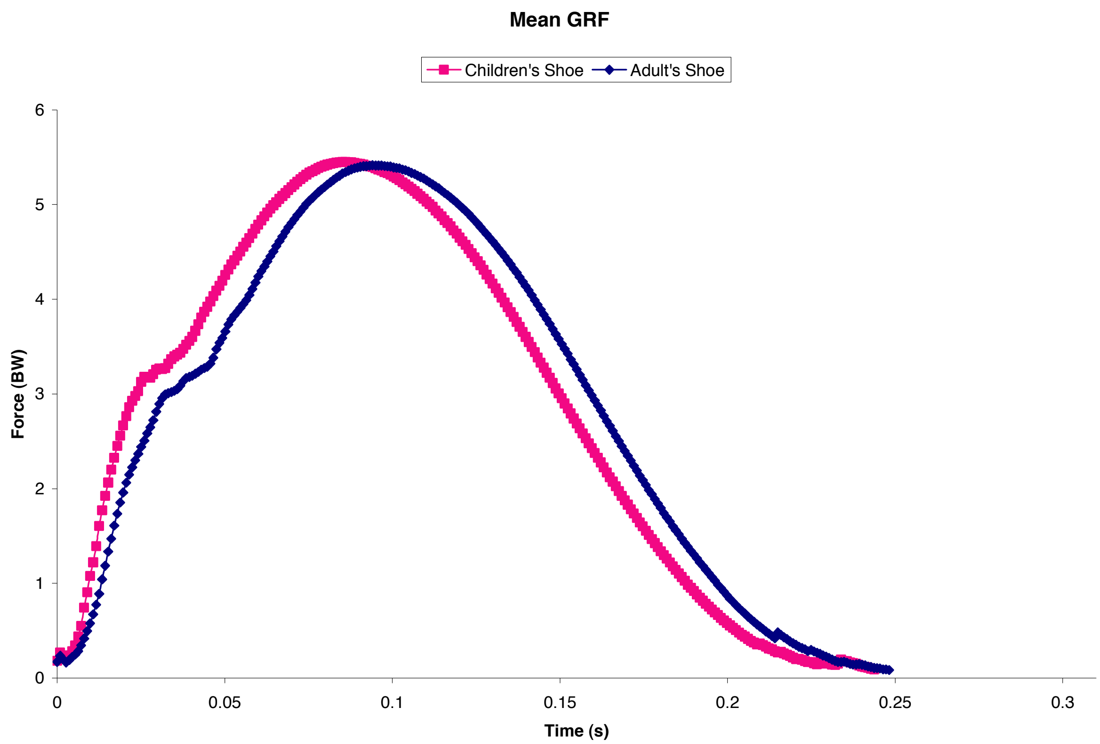
Subject #1




**Mean ± Standard Deviation for 10 Trials**

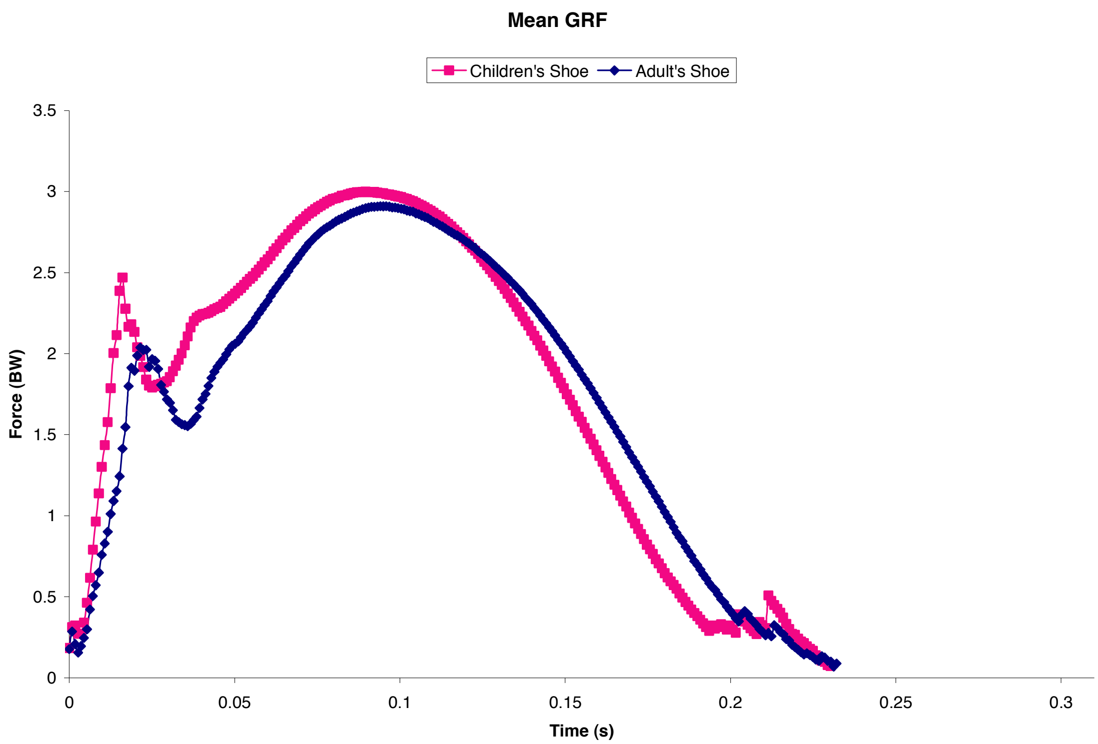
| | Children's Shoe | Adult's Shoe |
|---|---|---|
| F1 (N) | 3.89 ± 0.50 | 3.74 ± 0.39 |
| F2 (N) | 5.67 ± 0.18 | 5.37 ± 0.17 |
| Loading Rate (BW/s) | 154.21 ± 57.54 | 108.04 ± 26.01 |
| Stance Time (s) | 0.22 ± 0.01 | 0.23 ± 0.01 |
| Average VGRF (N) | 3.33 ± 0.18 | 2.97 ± 0.35 |
| | | |
| LR Bin 1 (BW/s) | 48.92 ± 20.16 | 37.02 ± 13.83 |
| LR Bin 2 (BW/s) | 146.97 ± 64.02 | 76.75 ± 32.80 |
| LR Bin 3 (BW/s) | 94.92 ± 38.35 | 89.05 ± 36.35 |
| LR Bin 4 (BW/s) | 88.61 ± 21.18 | 60.17 ± 41.74 |
| LR Bin 5 (BW/s) | 34.41 ± 1.73 | 65.41 ± 49.15 |

Subject #2




| | **Mean ± Standard Deviation** Children's Shoe | Adult's Shoe |
|---|---|---|
| F1 (N) | 3.35 ± 0.49 | 2.83 ± 0.46 |
| F2 (N) | 5.48 ± 0.12 | 5.47 ± 0.22 |
| Loading Rate (BW/s) | 143.94 ± 47.79 | 94.94 ± 36.36 |
| Stance Time (s) | 0.23 ± 0.01 | 0.23 ± 0.01 |
| Average VGRF (N) | 3.05 ± 0.09 | 3.00 ± 0.11 |
| | | |
| LR Bin 1 (BW/s) | 80.75 ± 51.31 | 36.21 ± 19.39 |
| LR Bin 2 (BW/s) | 173.35 ± 39.58 | 136.35 ± 80.51 |
| LR Bin 3 (BW/s) | 84.46 ± 54.30 | 103.52 ± 27.86 |
| LR Bin 4 (BW/s) | 60.12 ± 16.23 | 58.33 ± 1.99 |
| LR Bin 5 (BW/s) | 52.95 ± 24.32 | 13.99 ± 0.00 |

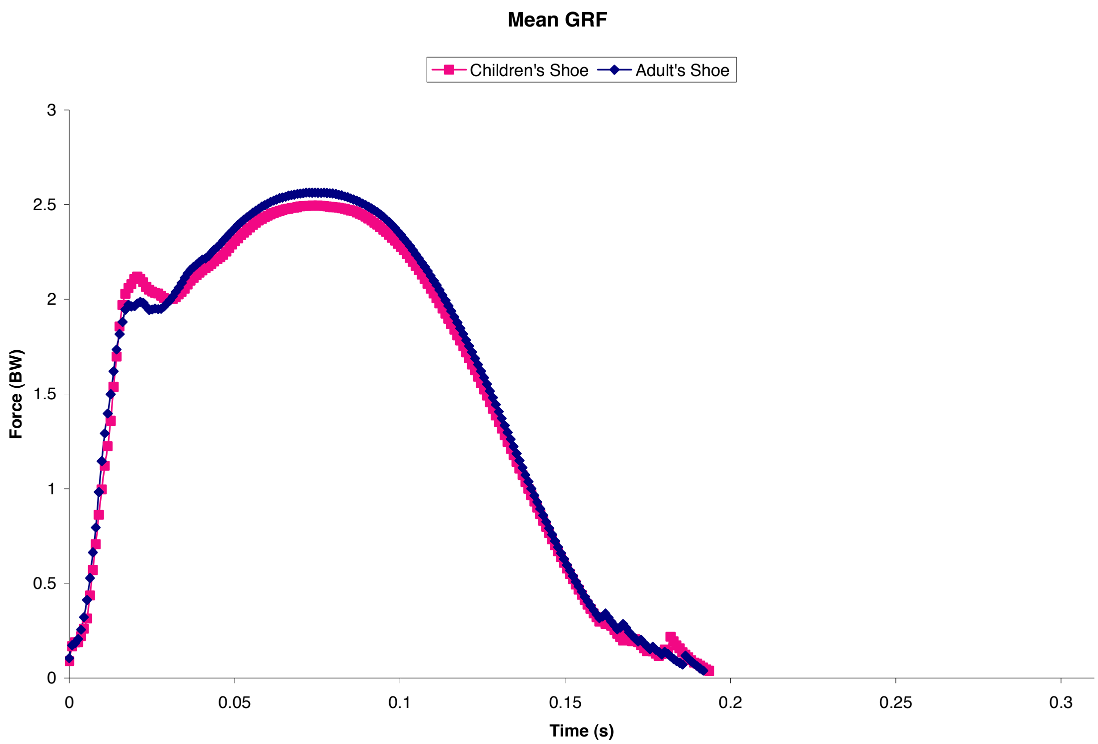
Subject #3




**Mean ± Standard Deviation**

| | Children's Shoe | Adult's Shoe |
|---|---|---|
| F1 (N) | 3.05 ± 1.06 | 2.79 ± 1.06 |
| F2 (N) | 3.02 ± 0.17 | 2.93 ± 0.19 |
| Loading Rate (BW/s) | 189.72 ± 66.95 | 132.13 ± 60.87 |
| Stance Time (s) | 0.20 ± 0.11 | 0.22 ± 0.01 |
| Average VGRF (N) | 1.96 ± 0.13 | 1.83 ± 0.09 |
| | | |
| LR Bin 1 (BW/s) | 106.40 ± 57.59 | 52.75 ± 24.12 |
| LR Bin 2 (BW/s) | 88.08 ± 83.15 | 108.01 ± 57.79 |
| LR Bin 3 (BW/s) | 41.66 ± 0.00 | 50.04 ± 0.00 |
| LR Bin 4 (BW/s) | 31.31 ± 0.00 | 26.11 ± 0.00 |
| LR Bin 5 (BW/s) | 18.22 ± 0.00 | 28.49 ± 0.00 |

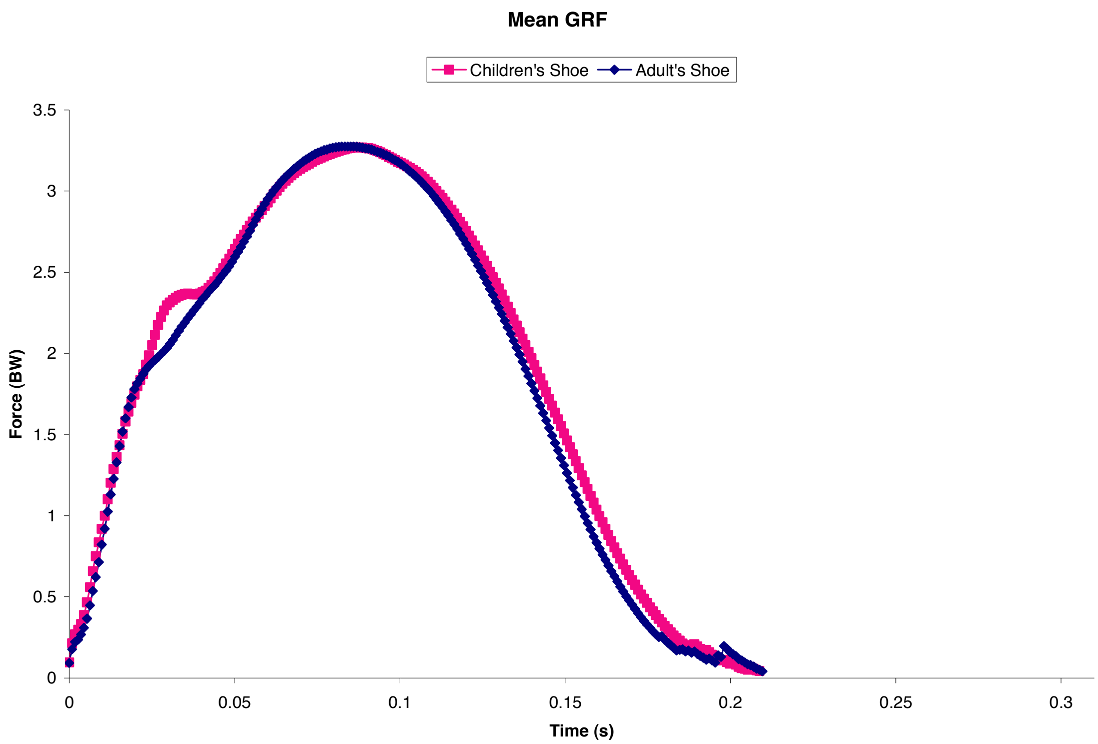
Subject #4




**Mean ± Standard Deviation**

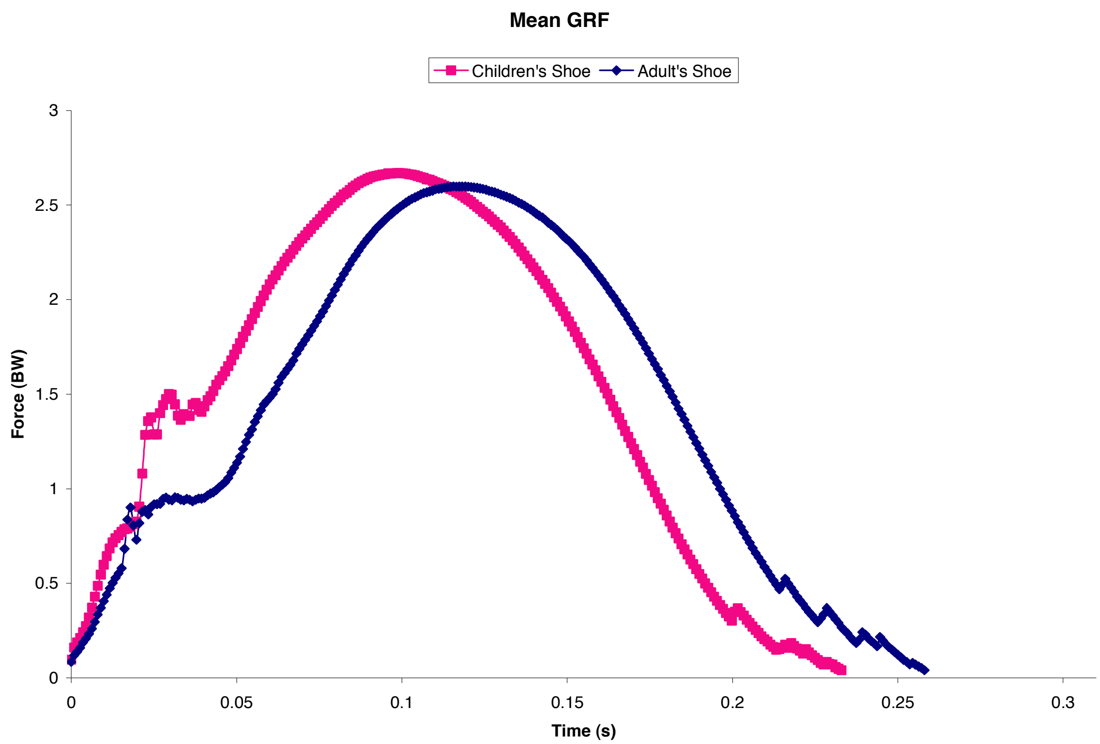
| | Children's Shoe | Adult's Shoe |
|---|---|---|
| F1 (N) | 2.38 ± 0.26 | 2.39 ± 0.63 |
| F2 (N) | 2.52 ± 0.21 | 2.60 ± 0.16 |
| Loading Rate (BW/s) | 136.71 ± 48.39 | 139.25 ± 52.66 |
| Stance Time (s) | 0.17 ± 0.01 | 0.17 ± 0.01 |
| Average VGRF (N) | 1.65 ± 0.14 | 1.70 ± 0.12 |
| LR Bin 1 (BW/s) | 66.94 ± 19.00 | 97.92 ± 51.58 |
| LR Bin 2 (BW/s) | 151.03 ± 13.46 | 119.23 ± 35.52 |
| LR Bin 3 (BW/s) | 0.00 ± 0.00 | 51.43 ± 24.16 |
| LR Bin 4 (BW/s) | 0.00 ± 0.00 | 33.761± 0.00 |
| LR Bin 5 (BW/s) | 0.00 ± 0.00 | 12.34 ± 0.004 |

Subject #5




| | Mean ± Standard Deviation | |
|---|---|---|
| | Children's Shoe | Adult's Shoe |
| F1 (N) | 2.17 ± 0.41 | 2.05 ± 0.39 |
| F2 (N) | 3.30 ± 0.14 | 3.32 ± 0.12 |
| Loading Rate (BW/s) | 97.67 ± 32.92 | 90.18 ± 14.06 |
| Stance Time (s) | 0.20 ± 0.01 | 0.19 ± 0.01 |
| Average VGRF (N) | 2.00 ± 0.19 | 1.99 ± 0.07 |
| | | |
| LR Bin 1 (BW/s) | 82.60 ± 50.85 | 69.38 ± 11.23 |
| LR Bin 2 (BW/s) | 105.71 ± 26.95 | 103.20 ± 30.63 |
| LR Bin 3 (BW/s) | 113.19 ± 0.00 | 52.07 ± 27.13 |
| LR Bin 4 (BW/s) | 0.00 ± 0.00 | 63.81 ± 16.02 |
| LR Bin 5 (BW/s) | 0.00 ± 0.00 | 25.64 ± 7.35 |

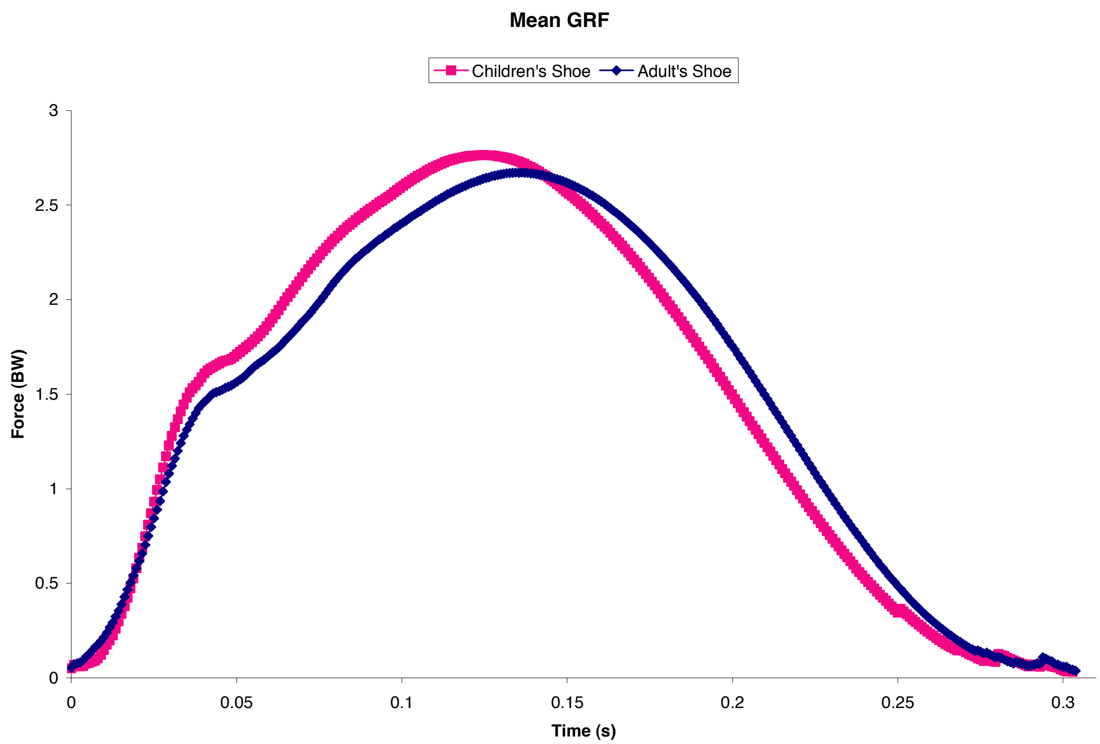
Subject #6




**Mean ± Standard Deviation**

| | Children's Shoe | Adult's Shoe |
|---|---|---|
| F1 (N) | 2.30 ± 0.61 | 1.24 ± 0.83 |
| F2 (N) | 2.71 ± 0.25 | 2.66 ± 0.10 |
| Loading Rate (BW/s) | 89.14 ± 33.87 | 48.66 ± 54.00 |
| Stance Time (s) | 0.21 ± 0.11 | 0.23 ± 0.01 |
| Average VGRF (N) | 1.62 ± 0.14 | 1.53 ± 0.10 |
| | | |
| LR Bin 1 (BW/s) | 50.18 ± 27.14 | 31.97 ± 22.13 |
| LR Bin 2 (BW/s) | 27.16 ± 21.89 | 30.78 ± 15.87 |
| LR Bin 3 (BW/s) | 28.18 ± 28.37 | 29.21 ± 7.87 |
| LR Bin 4 (BW/s) | 27.36 ± 0.00 | 35.53 ± 8.43 |
| LR Bin 5 (BW/s) | 12.01 ± 0.00 | 0.00 ± 0.00 |

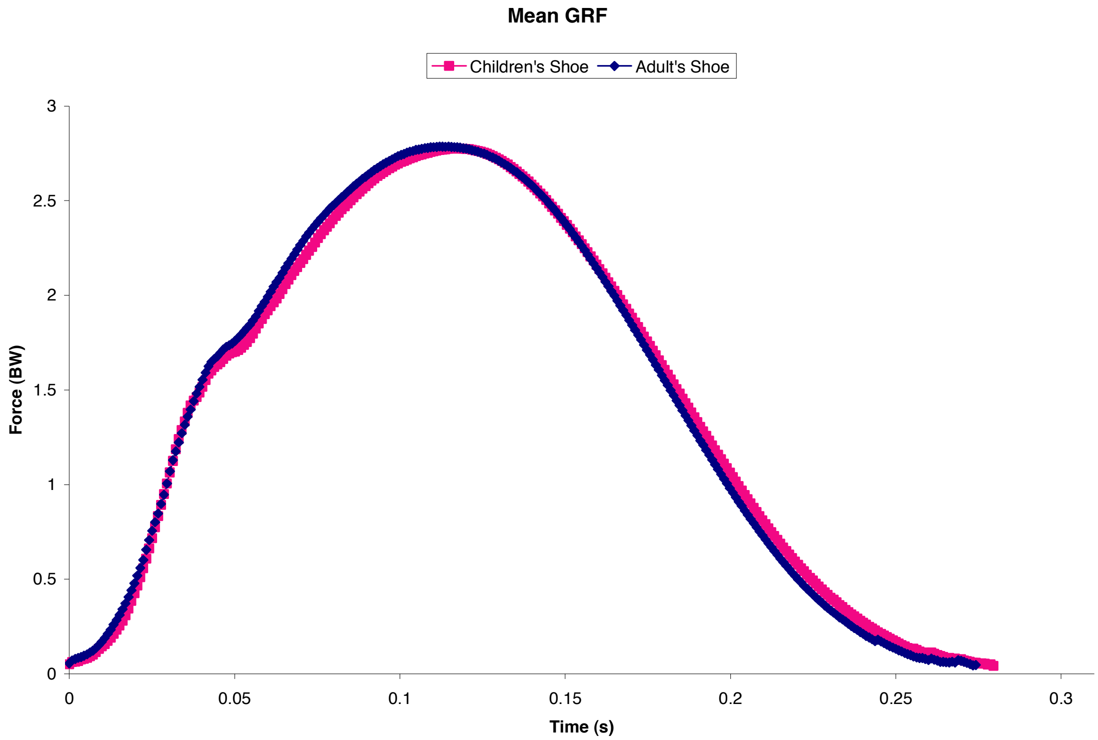
Subject #7




**Mean ± Standard Deviation**

| | Children's Shoe | Adult's Shoe |
|---|---|---|
| F1 (N) | 1.64 ± 0.11 | 1.63 ± 0.19 |
| F2 (N) | 2.79 ± 0.14 | 2.68 ± 0.13 |
| Loading Rate (BW/s) | 39.97 ± 5.56 | 37.30 ± 4.89 |
| Stance Time (s) | 0.28 ± 0.01 | 0.29 ± 0.01 |
| Average VGRF (N) | 1.58 ± 0.10 | 1.56 ± 0.07 |
| | | |
| LR Bin 1 (BW/s) | 7.92 ± 3.85 | 15.61 ± 5.12 |
| LR Bin 2 (BW/s) | 41.09 ± 14.79 | 35.12 ± 11.97 |
| LR Bin 3 (BW/s) | 65.48 ± 12.88 | 50.25 ± 9.92 |
| LR Bin 4 (BW/s) | 42.86 ± 17.98 | 39.48 ± 8.85 |
| LR Bin 5 (BW/s) | 27.85 ± 12.12 | 18.32 ± 2.83 |

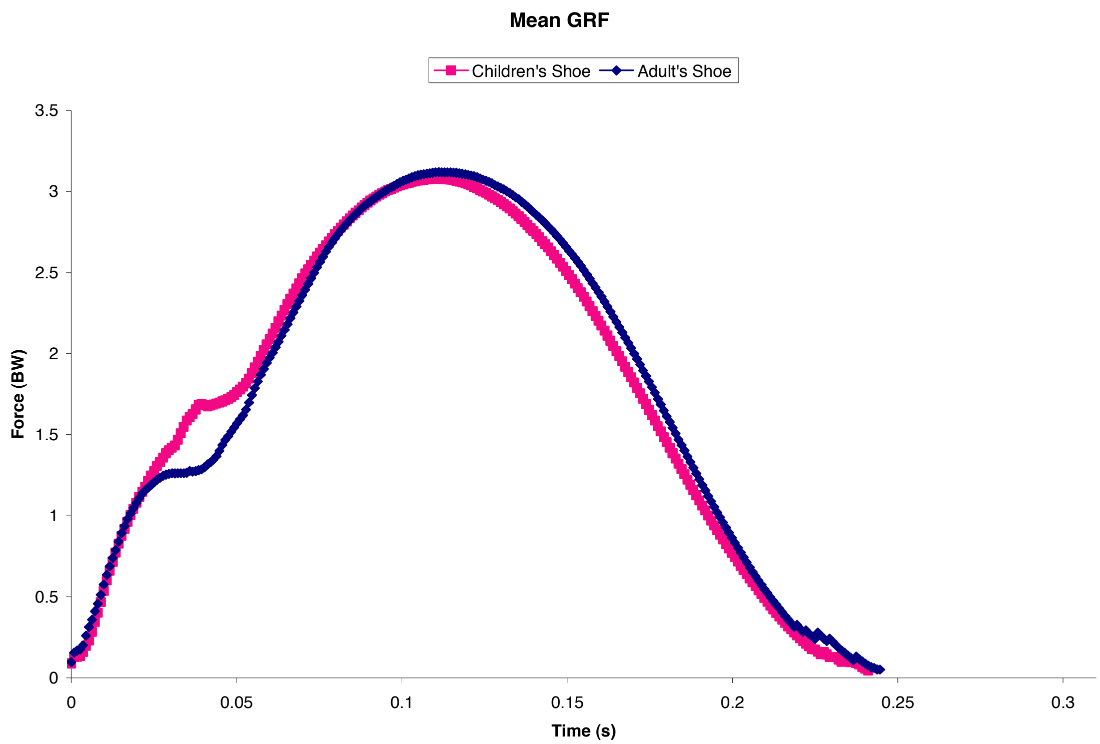
Subject #8




**Mean ± Standard Deviation**

| | Children's Shoe | Adult's Shoe |
|---|---|---|
| F1 (N) | 1.69 ± 0.13 | 1.73 ± 0.16 |
| F2 (N) | 2.79 ± 0.08 | 2.80 ± 0.07 |
| Loading Rate (BW/s) | 39.16 ± 4.50 | 37.67 ± 6.27 |
| Stance Time (s) | 0.27 ± 0.01 | 0.26 ± 0.01 |
| Average VGRF (N) | 1.50 ± 0.06 | 1.53 ± 0.05 |
| | | |
| LR Bin 1 (BW/s) | 9.06 ± 2.53 | 10.80 ± 3.31 |
| LR Bin 2 (BW/s) | 25.66 ± 13.91 | 29.35 ± 9.45 |
| LR Bin 3 (BW/s) | 57.36 ± 17.40 | 51.22 ± 16.13 |
| LR Bin 4 (BW/s) | 54.45 ± 13.69 | 54.24 ± 11.32 |
| LR Bin 5 (BW/s) | 45.89 ± 20.99 | 43.30 ± 13.78 |

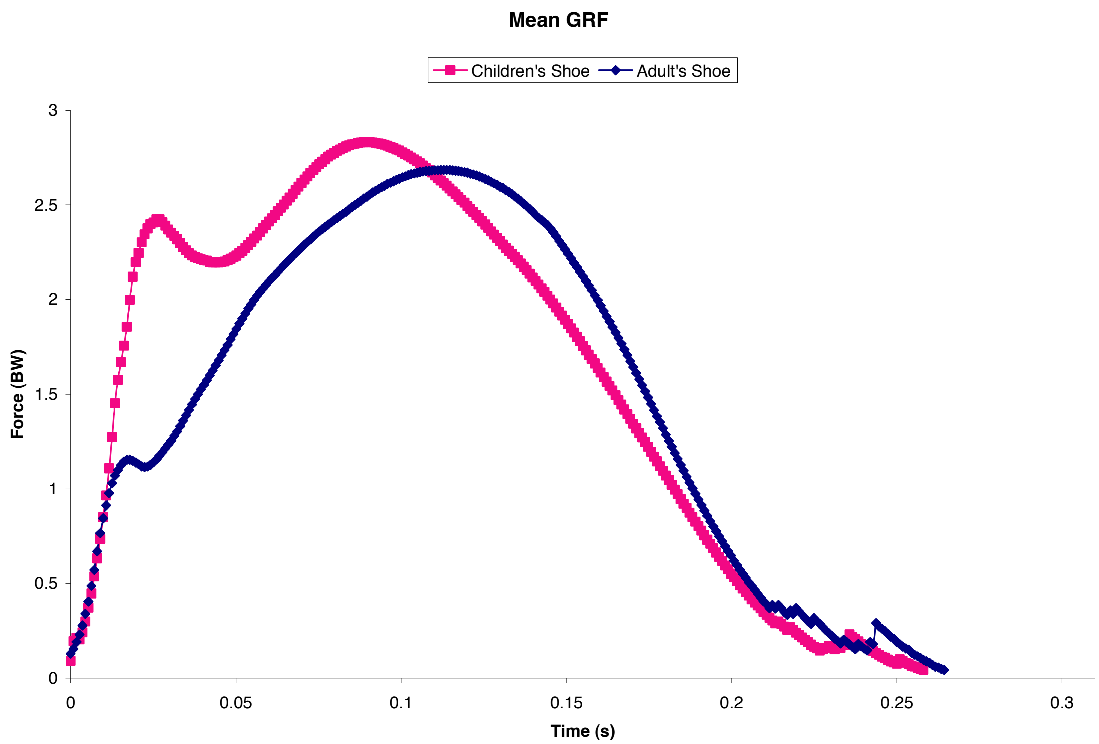
Subject #9




**Mean ± Standard Deviation**

| | Children's Shoe | Adult's Shoe |
|---|---|---|
| F1 (N) | 1.64 ± 0.26 | 1.32 ± 0.26 |
| F2 (N) | 3.08 ± 0.13 | 3.16 ± 0.17 |
| Loading Rate (BW/s) | 46.58 ± 7.72 | 42.14 ± 6.15 |
| Stance Time (s) | 0.23 ± 0.01 | 46.32 ± 9.72 |
| Average VGRF (N) | 1.80 ± 0.09 | 1.84 ± 0.10 |
| | | |
| LR Bin 1 (BW/s) | 40.34 ± 15.35 | 46.32 ± 9.72 |
| LR Bin 2 (BW/s) | 58.60 ± 13.92 | 54.21 ± 8.73 |
| LR Bin 3 (BW/s) | 32.70 ± 12.28 | 28.88 ± 10.58 |
| LR Bin 4 (BW/s) | 34.59 ± 6.46 | 17.58 ± 0.00 |
| LR Bin 5 (BW/s) | 29.54 ± 0.00 | 0.00 ± 0.00 |

Subject #10




| | **Mean ± Standard Deviation** Children's Shoe | Adult's Shoe |
|---|---|---|
| F1 (BW) | 2.55 ± 0.18 | 1.22 ± 0.13 |
| F2 (BW) | 2.88 ± 0.12 | 2.71 ± 0.10 |
| Loading Rate (BW/s) | 121.21 ± 29.96 | 67.50 ± 15.11 |
| Stance Time (s) | 0.23 ± 0.01 | 0.23 ± 0.02 |
| Average VGRF (N) | 1.76 ± 0.05 | 1.67 ± 0.07 |
| | | |
| LR Bin 1 (BW/s) | 71.89 ± 30.87 | 71.12 ± 15.11 |
| LR Bin 2 (BW/s) | 132.43 ± 36.21 | 44.06 ± 9.43 |
| LR Bin 3 (BW/s) | 0.00 ± 0.00 | 20.58 ± 0.00 |
| LR Bin 4 (BW/s) | 0.00 ± 0.00 | 33.44 ± 0.00 |
| LR Bin 5 (BW/s) | 0.00 ± 0.00 | 26.49 ± 0.00 |

APPENDIX III

MATLAB

```
%Program written to analyze Kistler Force Plate data
%Data are generated via Kistler Bioware software package.
%This program calls <run2008onedf.m> <my_open2df.m> and <my_savedf.m>

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


temporary_directory = pwd;         %Set temporary directory to the present working
directory
fprintf(1,'\n\nProcessing\n\n');    %Tell the user the program is running

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

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

        %File information
                outputfile1     = 'allonedf.txt';    %name of the file that will contain your
final information for force plate
      directory  = 'c:\biomech\forrest'; %this is the directory where the files are located
                datain          = '.txt';
                dataout         = '.grf';
                savedata        = 'yes';          %indicate if summary data should be saved
                savefiles       = 'yes';          %indicate if data per file should be saved
                headers         = 15;             %number of headers in the .txt files that are
being opened and analyzed
                fs                  = 1116;                     %sample frequency
                Fzcutoff        = 20;                   %value to identify HC and TO (starts
counting at first number greater than 20N)
           peakcol       = 4;                       %Number of channels and time
                peakrow         = inf;                  %should be about 5 s worth of data
                precision       = 4;                    %output precision
                g               = -9.8;                 %acceleration due to gravity

        %==================================================
```

```
%                    Main Processing Loop
%================================================

%counter
filenumber = 0;     % this counter is for the file number
q= 0;               % this counter is for the figure number

for s = startwithsubj:(startwithsubj+subjects-1)
BW = input('enter subject body weight in lbs: ');
BW = BW*4.448;          % converts subject's body weight to Newtons

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

        filenumber = filenumber+1;

        %Open a file
        [data, inputfileroot] = my_open2df(s, c, t, directory, datain, dataout,
        peakcol, peakrow, headers);

        %Analysis
        run2008onedf;    % Integrated Force Platform
totalone = total; % saves data from run2008onedf as totalone
%output data using a function 'my_savedf'

%calculate loading rate
lr = loadingrate(time, Fz, F1, F1pos, fs);

alldata(filenumber,:) = [totalone(filenumber,:) lr];

        %clean up before next file
        clear    data F1 F1pos Fz HC TO ...

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

%==========================================
%       End of Main Processing Loop
%==========================================

%output data using a function 'my_savedf'
if strcmp(savedata,'yes')
        my_savedf(directory, outputfile1, 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');

	%clc;
   %clear;



%run2008onedf.m
%
%This program runs a series of commands that picks off certain variables out of
%a GRF file recorded via Kistler Bioware.
%
%This program is called via ForrestThesisGRF.m
%
%This program calls <findHCTOdf.m> which is a program that locates Heel
%Contact and Toe Off
%
%Variables calculated are:
%	Stance time
%	Stance phase data saved per subject, condition, trial
%	Fz: F1 & Favg (and times to each variable from HC, in msec)

clc
fprintf(1,'\n\nRunning run-walk routine.\n\n'); %Tell the user the program is running

%Data are organized as:
%	time Fz
%First, identify where Fz is > cutoff force
%Then, search backwards for TO as Fz < cutoff force
%Take out that section and send data to *.grf
%Find F1 at that position and export
%plot the data, and confirm that it is OK.

			%identify window size to search (+/- ...)
				searchwindow=.5;

			%function to find heel contact and toe off markers
				Fz = data(:,4);
```

```
                [HC, TO] = findHCTOdf(Fz, Fzcutoff);

        stancetime = (TO-HC)/fs;
        stancerows = TO-HC+1;


        %assign variables
           Fz = data(HC:TO,4)./BW;

        %adjust times such that HC is zero.
                to = (TO - HC)/fs;
                hc = 0;
                time_interval = 1/fs;
                time = hc:time_interval:to;

%---------------------Plot Data-------------------------
   % update the counter for the figure number
      q = q + 1;
   % create a figure name
   figure(q);
        plot(time,Fz, 'g')
   %, time, Fy, 'k')
        title(['Ground Reaction Forces ', num2str(inputfileroot),' one']);
        xlabel('time(s)')
        ylabel('Force (N)')
        hold on

      %----------------------Fz GRF---------------------------

% initialize value
pos = 0;
searchwindow = 5;
%----------------------F1 PEAK--------------------------%
   hold on
    % ask the user if a F1(first normal maximum impact force peak) will be calculated
   pos = input('\nEnter 1 to calculate F1 peak, Enter 0 if F1 peak is NOT present: ');
   if pos == 1
   % ask the user to click on F1
   fprintf(1,'\nClick near F1 (first normal maximum impact force)\n')
   [xpos, ypos] = ginput(1);
   xpos = round(xpos*fs);
   start = xpos-searchwindow;
      if (start<1)
         start=1;
      end
```

```
    peak = max(Fz(start:xpos+searchwindow));
    temppeakpos = find(Fz(start:xpos+searchwindow)==peak);
    temppeakpos(5)=0;
    peakpos = temppeakpos(1);
    peakpos = peakpos+(start)-1;
    F1pos= time(peakpos);
    F1= Fz(peakpos);
    plot(F1pos,F1, 'ro')

elseif pos == 0
     fprintf (1, '\nNo F1 Peak\n')
  end

    % set dummy value for F1 peak so when there is none, the data can still be saved
    if pos      ==  0
       F1      = 0;
       F1pos   = 0;
    end

    % ask the user to click on F2 = second normal maximum impact force
    fprintf(1,'\nClick near F2 (second normal maximum impact force)\n')
    [xpos, ypos] = ginput(1);
    xpos = round(xpos*fs);
    start = xpos-searchwindow;
       if (start<1)
          start=1;
       end
    peak = max(Fz(start:xpos+searchwindow));
    temppeakpos = find(Fz(start:xpos+searchwindow)==peak);
    temppeakpos(5)=0;
    peakpos = temppeakpos(1);
    peakpos = peakpos+(start)-1;
    F2pos= time(peakpos);
    F2= Fz(peakpos);
    plot(F2pos, F2, 'ro')

  %--------------------Average Fz-------------------------------

                %calculate average Fz during stance
                         Fz_avg = mean(Fz);


                hold off

                fprintf(1,'\nHit enter to continue.\n');
                pause
```

```
                    time = time';

          %----------------------Save Stance Phase Data per S,C,T---------------------

                    grfdata = [time Fz];

          grfout = [inputfileroot 'one.grf'];

                    %output *.grf data
                    %these files will consist of stance data only for each trial
                 eval(['save ' grfout ' grfdata -ascii -double -tabs']);
                 fclose('all');

        %----------------------Save Plot for each trial ------------------------------------
          plotname = [inputfileroot 'one.fig'];
          hgsave(figure(q), plotname); % saves the figure

%----------------------Save composite data--------------------------------------------



          %save discrete variables
        total(filenumber,:) = [s c t stancetime F1 F1pos Fz_avg];

%close(gcf)
%Return control back to ForrestThesisGRF.m


%function used to calculate loading rate
%
%lr = calculated loading rate for 10 ms bins within 50 ms
%
%time = time of data set
%Fz
%F1time = time of F1 (when there is no F1, this will be zero)
%fs = sample rate

function [lr] = loadingrate(time, Fz, F1, F1time, fs)

%calculate loading when F1 is present
if F1 > 0

   lr(1) = F1 / F1time;

   %set the F1pos to row number
```

```
    F1pos = F1time*fs;

else

    lr(1) = 0;

    %set the position of F1 to greater than the 50 ms window
    F1pos = length(Fz);

end

    %calculate loading rate for 10 ms bins up to 50 ms
    st = 1;
    ed = round((.01 * fs));

for i = 1:5

    %calculate loading rate only if the F1 is NOT in the bin
    if F1pos > ed ;

        %calculate loading rate
        lr(i+1) = (Fz(ed) - Fz(st))/(time(ed) - time(st));

        %plot information
        x = [time(st), time(ed)];
        y = [Fz(st), Fz(ed)];

        %keep figure active
        hold on
        if i == 1
            plot(x, y, 'r')
        elseif i == 2
                plot(x,y, 'b')
            elseif i == 3
                    plot(x,y,'y')
                elseif i == 4
                        plot(x,y,'c')
                    elseif i == 5
                            plot(x,y,'k')
                        end

        %update start and stop of bin
        st = ed;
        ed = round(ed + (.01 * fs));

    else
```

```
        %don't caclulate loading rate if F1 falls in a bin
        lr(i+1) = 0;
        st = ed;
        ed = round(ed + (.01 * fs));

    end

end

pause
close(gcf)
```

# APPENDIX IV

# STATISTICAL ANALYSIS

**Paired Samples Statistics**

| | | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Pair 1 | F1C1 | 2.464490 | 10 | .7637396 | .2415157 |
| | F1C2 | 2.091480 | 10 | .8345912 | .2639209 |
| Pair 2 | F2C1 | 3.422440 | 10 | 1.1555515 | .3654175 |
| | F2C2 | 3.368130 | 10 | 1.1061517 | .3497959 |
| Pair 3 | FZavgC1 | 2.026961 | 10 | .6376614 | .2016462 |
| | FZavgC2 | 1.969808 | 10 | .5803957 | .1835372 |
| Pair 4 | LoadingRateC1 | 105.8476 | 10 | 52.30513 | 16.54034 |
| | LoadingRateC2 | 79.7786 | 10 | 38.76903 | 12.25984 |
| Pair 5 | StanceTimeC1 | .224234 | 10 | .0316686 | .0100145 |
| | StanceTimeC2 | .228886 | 10 | .0316880 | .0100206 |

**Paired Samples Correlations**

| | | N | Correlation | Sig. |
|---|---|---|---|---|
| Pair 1 | F1C1 & F1C2 | 10 | .832 | .003 |
| Pair 2 | F2C1 & F2C2 | 10 | .996 | .000 |
| Pair 3 | FZavgC1 & FZavgC2 | 10 | .993 | .000 |
| Pair 4 | LoadingRateC1 & LoadingRateC2 | 10 | .890 | .001 |
| Pair 5 | StanceTimeC1 & StanceTimeC2 | 10 | .959 | .000 |

**Descriptive Statistics**

| | Mean | Std. Deviation | N |
|---|---|---|---|
| C1Bin1 | 50.6104 | 43.50789 | 5 |
| C1Bin2 | 95.0283 | 64.42356 | 5 |
| C1Bin3 | 68.7736 | 21.25140 | 5 |
| C1Bin4 | 56.1123 | 21.16106 | 5 |
| C1Bin5 | 35.8656 | 13.87317 | 5 |
| C2Bin1 | 30.6772 | 17.27723 | 5 |
| C2Bin2 | 77.1127 | 46.12032 | 5 |
| C2Bin3 | 68.8180 | 25.59485 | 5 |
| C2Bin4 | 47.6585 | 14.52876 | 5 |
| C2Bin5 | 33.9053 | 20.91042 | 5 |

**Tests of Within-Subjects Contrasts**

Measure:MEASURE_1

| Source | shoe | bin | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|---|
| shoe | Linear | bin | 1162.518 | 1 | 1162.518 | 6.229 | .067 | .609 | 6.229 | .476 |
| Error(shoe) | Linear | bin | 746.546 | 4 | 186.637 | | | | | |
| bin | shoe * bin | Linear | 2088.656 | 1 | 2088.656 | .768 | .430 | .161 | .768 | .105 |
| | | Quadratic | 11069.659 | 1 | 11069.659 | 11.638 | .027 | .744 | 11.638 | .724 |
| | | Cubic | 3920.250 | 1 | 3920.250 | 3.593 | .131 | .473 | 3.593 | .308 |
| | | Order 4 | 576.389 | 1 | 576.389 | 1.529 | .284 | .277 | 1.529 | .161 |
| Error(bin) | shoe * bin | Linear | 10881.430 | 4 | 2720.358 | | | | | |
| | | Quadratic | 3804.715 | 4 | 951.179 | | | | | |
| | | Cubic | 4364.871 | 4 | 1091.218 | | | | | |
| | | Order 4 | 1507.674 | 4 | 376.918 | | | | | |
| shoe * bin | Linear | Linear | 515.462 | 1 | 515.462 | 2.111 | .220 | .345 | 2.111 | .203 |
| | | Quadratic | 54.726 | 1 | 54.726 | .095 | .773 | .023 | .095 | .057 |
| | | Cubic | .226 | 1 | .226 | .001 | .977 | .000 | .001 | .050 |
| | | Order 4 | 251.103 | 1 | 251.103 | .933 | .389 | .189 | .933 | .117 |
| Error(shoe*bin) | Linear | Linear | 976.896 | 4 | 244.224 | | | | | |
| | | Quadratic | 2299.656 | 4 | 574.914 | | | | | |
| | | Cubic | 961.721 | 4 | 240.430 | | | | | |
| | | Order 4 | 1076.899 | 4 | 269.225 | | | | | |

a. Computed using alpha = .05

**Pairwise Comparisons**

Measure:MEASURE_1

| (I) bin | (J) bin | Mean Difference (I-J) | Std. Error | Sig.[a] | 95% Confidence Interval for Difference[a] Lower Bound | Upper Bound |
|---|---|---|---|---|---|---|
| 1 | 2 | -45.427 | 15.794 | .370 | -133.273 | 42.420 |
| | 3 | -28.152 | 15.624 | .793 | -115.055 | 58.751 |
| | 4 | -11.242 | 17.096 | 1.000 | -106.330 | 83.847 |
| | 5 | 5.758 | 15.797 | 1.000 | -82.109 | 93.626 |
| 2 | 1 | 45.427 | 15.794 | .370 | -42.420 | 133.273 |
| | 3 | 17.275 | 17.942 | .993 | -82.524 | 117.073 |
| | 4 | 34.185 | 22.644 | .900 | -91.765 | 160.135 |
| | 5 | 51.185 | 24.047 | .653 | -82.567 | 184.937 |
| 3 | 1 | 28.152 | 15.624 | .793 | -58.751 | 115.055 |
| | 2 | -17.275 | 17.942 | .993 | -117.073 | 82.524 |
| | 4 | 16.910 | 5.525 | .319 | -13.823 | 47.644 |
| | 5 | 33.910 | 8.638 | .159 | -14.134 | 81.954 |
| 4 | 1 | 11.242 | 17.096 | 1.000 | -83.847 | 106.330 |
| | 2 | -34.185 | 22.644 | .900 | -160.135 | 91.765 |
| | 3 | -16.910 | 5.525 | .319 | -47.644 | 13.823 |
| | 5 | 17.000 | 4.048 | .129 | -5.517 | 39.517 |
| 5 | 1 | -5.758 | 15.797 | 1.000 | -93.626 | 82.109 |
| | 2 | -51.185 | 24.047 | .653 | -184.937 | 82.567 |
| | 3 | -33.910 | 8.638 | .159 | -81.954 | 14.134 |
| | 4 | -17.000 | 4.048 | .129 | -39.517 | 5.517 |

Based on estimated marginal means

a. Adjustment for multiple comparisons: Sidak.

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## VITA

Graduate College
University of Nevada, Las Vegas

Dana Forrest

Local Address:
62 East Serene Ave #432
Las Vegas, NV 89123

Home Address:
1713 Newfield Ave
Stamford, CT 06903

Degrees:
Bachelor of Science, Kinesiology, 2007

Special Honors and Awards:
Forrest, D. M. Knee Flexion and Extension Muscle Activity During Running at Simulated Microgravity. Graduate & Professional Student Association, Travel to professional Conference ($350).

Forrest, D. M. Muscle Activity During Running At Reduced Body Weight. Medicine and Science in Sports and Exercise, Graduate & Professional Student Association, Travel to professional Conference ($500).

Publications:
Forrest, D.M., Dufek, J.S., Masumoto, K., Mercer, J.A. (2009). Muscle Activity During Running At Reduced Body Weight. Medicine and Science in Sports and Exercise, Volume 41:5 Supplement.

Thesis Title: Ground Reaction Forces for Children Running in Different Shoes

Thesis Examination Committee:
Chairperson, Dr. John Mercer
Committee Member, Dr. Janet Dufek
Committee Member, Dr. Richard Tandy
Graduate Faculty Representative, Dr. Edward Neumann