Shock Attenuation in Landing

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SHOCK ATTENUATION

IN

LANDING

by

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ABSTRACT

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Shock attenuation (SA) has been well studied in activities such as walking and running (Chu, et al. 2004; Derrick, et al. 2004; Mercer, et al. 2003); however, there is a lack of research regarding SA during landing. Furthermore, there is lack of information regarding which structures attenuate shock. The purpose of this study was to examine SA among the leg-hip, hip-head, and leg-head segments during landing. Each subject (n=10, Age 26.3 ± 2.71 years, Height 1.68 ± 0.08 m, Mass 70.49 ± 16.03 kg) was instrumented with accelerometers at the leg, hip and forehead. Subjects then performed landings from three heights: 30cm, 60cm, and 90cm. For each height, subjects completed 5 landing trials. Rest was provided between each trial. Order of conditions was randomized to account for fatigue and learning. During each landing, accelerations were recorded at 1000 Hz for the leg, hip, and head respectively using light-weight accelerometers. Data were reduced by identifying the peak impact accelerations for the leg (PkLeg), hip (PkHip), and head (PkHead). After peak impact accelerations were identified, SA was calculated for three locations using the following formulas: Total (between leg and head) = [1-PkHd/PkLeg]*100, Lower (between leg and hip) = [1-PkHip/PkLeg]*100, Upper (between hip and head) = [1-PkHd/PkHip]*100. Peak impact accelerations as well as SA were the dependent variables. There were three levels of independent variable height (30 cm, 60 cm, and 90 cm) and location (leg, hip, and head for peak impact accelerations; total, lower, and upper-body for SA). Variables were compared using repeated measures ANOVA ($\alpha=0.05$). It was determined that there was an interaction between height and location for peak impact acceleration ($p<0.05$) but not for SA ($p>0.05$). Peak impact accelerations across all locations increased with an increase in height ($p<0.05$). It was also determined that total and lower body SA increased with an increase in height ($p<0.05$) but upper-body SA did not ($p>0.05$) With an overall increase in peak impact accelerations at all locations, and an increase in total and lower-body SA, but not upper-body SA, it appears the lower extremity is primarily responsible for the attenuation of the impacts resulting from landing

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CHAPTER 1

INTRODUCTION

Shock attenuation (SA) has been well studied in activities such as walking and running (Chu et al. 2004; Derrick 2004; Flynn et al. 2004; Mercer et al. 2003; Mercer et al. 2002) because it describes the process of reducing the impact force seen at each foot strike. These impact forces can be high in magnitude; for example, the magnitude of the vertical component of the ground reaction force at impact during running can be 3 to 5 times body weight (Cavanagh et al. 1980). Interestingly, the act of landing from a jump has much larger impact forces (McNitt-Gray, 1989) compared to running but there is little research on shock attenuation during landing.

Zhang et al. (2008) examined shock transmission and reduction during landing with varied mechanical demands. Shock transmission is the inverse of shock attenuation, shock transmission of 20% would be the same as shock attenuation of 80%. Zhang et al. (2008) reported that the peaks of the vertical ground reaction force, forehead and tibial accelerations as well as eccentric muscle work by lower extremity joints were all greater with increased landing heights. However, shock transmission had minimal changes across five landing heights. Because SA is the ratio of head and leg impact accelerations, the observation of no change in SA means that head and leg impact accelerations are increase at a similar rate as landing height also increases. With an increase in GRF but a lack of compensation in SA, the body must attenuate more overall force. Unlike the responses observed during walking and running (Shorten et al. ,1989), there was no significant difference in SA with elevated mechanical demands during landing.

Coventry et al. (2006) examined the effect of fatigue on shock attenuation during single leg landings. The researchers attached accelerometers to the head and lower leg of subjects, and had them perform various landing activities until fatigue was reached. Subjects reached a fatigued state, however there was no significant difference in shock attenuation throughout the states of the activity. Results of this study are similar to results attained in another study, where shock attenuation was not significantly different across five landing heights (Zhang et al, 2008).

Dufek et al. (2008) observed impact characteristics in females, running at different speeds. Interestingly, Dufek added a third accelerometer to their design breaking the body into lower extremity and back segments. It was observed that adult females had a greater percentage of attenuation in the back compared to the lower extremity. Under the greater demands of landing, it is unknown if this would still hold true.

The current research on SA during landing or running has been largely focused only on the attenuation between the leg and head segments (Chu, et al. 2004; Coventry, et al. 2006; Derrick, 2004; Flynn, et al. 2004; Mercer, et al. 2003; Mercer, et al. 2002; Zhang, et al. 2005). Since the lower extremity is largely responsible for absorbing impact energy, it makes sense to understand SA characteristics among different segments. This information would be helpful to determine where in the body the shock from impact events is being attenuated and hence lead to a better understanding of shock attenuation mechanisms.

Purpose of the Study

The purpose of this study was to determine SA characteristics among different segments while landing from varied heights. Specifically, the unique aspect of this study was that SA was examined between leg-hip, hip-head, as well as leg-head locations. Furthermore, impact characteristics were measured and examined in order to understand SA parameters. Because of the more specific localized focus on body locale, the outcome of this study may present an improved way to measure SA

Research Hypotheses

The Research hypotheses of this study are:

1. Leg peak impact acceleration is influenced by height of landing
2. Hip peak impact acceleration is influenced by height of landing
3. Head peak impact acceleration is influenced by height of landing
4. Total body SA is influenced by height of landing
5. Lower body SA will be greater than upper body SA at each height.

Null and alternate hypotheses for the study are:

H_{0LP} $\mu_{30cm} = \mu_{60cm} = \mu_{90cm}$	H_{0LP}: At Least Two Means will be Different
H_{0MP} $\mu_{30cm} = \mu_{60cm} = \mu_{90cm}$	H_{0MP}: At Least Two Means will be Different
H_{0HP} $\mu_{30cm} = \mu_{60cm} = \mu_{90cm}$	H_{0HP}: At Least Two Means will be Different
H_{0TSA} $\mu_{30cm} = \mu_{60cm} = \mu_{90cm}$	H_{0TSA}: At Least Two Means will be Different
$H_{0LBUBSA}$ $\mu_{30cm} = \mu_{60cm} = \mu_{90cm}$	H_{0TSA}: LBSA >UBSA μ_{30cm}, μ_{60cm}, μ_{90cm}

1. Independent variable: height (30 cm, 60 cm, 90 cm); location (leg, hip, head for peak impact acceleration; total, lower, upper body for SA)
2. Dependent variables: peak impact acceleration and shock attenuation

Definition of Terms

The following definitions are given for the purpose of clarification:

1. Acceleration: The rate of change in velocity.
2. Leg peak impact acceleration (PkLeg): Peak acceleration of the leg recorded by an accelerometer mounted on the medial aspect of the distal tibia immediately after ground contact.
3. Hip peak impact acceleration (PkHip): Peak acceleration of the Hip recorded by an accelerometer mounted on the anterior superior iliac spine immediately after ground contact.
4. Head peak impact acceleration (PkHead): Peak acceleration of the Head recorded by an accelerometer mounted on the forehead immediately after ground contact.
5. Shock Attenuation (SA): Shock attenuation (SA) is the process by which the impact shock caused by the collision between the foot and ground is reduced. Mathematically it is the measure of the reduction of the peak impact acceleration between two segments. The formula in the time domain is:

$$\text{Shock Attenuation (\%)} = 100^* \left(1 - \text{Peak}_{\text{Segment-A}} / \text{Peak}_{\text{Segment-B}}\right)$$

6. Shock Wave: A wave initiated by the foot-ground contact that travels through the musculoskeletal system up to the head.

CHAPTER 2

Review of Related Literature

All sports have one thing in common: Injuries (Bahr & Krosshaug, 2005). Never are non-contact injuries more prevalent than in sports that require a landing from some kind of height (Ryder, Johnson, Beynnon, & Ettlinger, 1997). Sports like basketball and volleyball that usually require a jump, and a subsequent landing, fall into this category and are leaders among ankle and knee injuries (Herman, Weinhold, Guskiewicz, Garrett, Bing, & Padua, 2008). The focus of this chapter is to review the literature related to understanding mechanisms of landing from a jump. Before discussing landing, some biomechanical concepts will be presented.

Ground Reaction Forces

According to Newton's principles, a force involves the interaction of two objects and produces a change in the state of motion of an object by pushing or pulling it (Hamill, 2003). In the event of landing, the body applies a force to the ground and in turn the ground applies a force back toward the body. That force is termed ground reaction force (GRF). In almost all terrestrial human movement, the individual is acted upon by the GRF at some time. This is the reaction force provided by the surface upon which one is moving (Hamill, 2003). The reason the aforementioned sports have such prevalent injuries is this GRF. At ground contact the body experiences a force from the ground pushing back up at it. The body has the ability to attenuate the force (Decker, Torry, Wyland, Sterett, & Steadman, 2003; Zhang, Derrick, Evans, & Yu, 2008). However, when doing so, some structures may be stressed beyond capacity due to improper technique resulting in opportunity for injury (Bahr & Krosshaug, 2005). Key papers will be examined to observe the role of GRF in landing and how it relates to injury in sport.

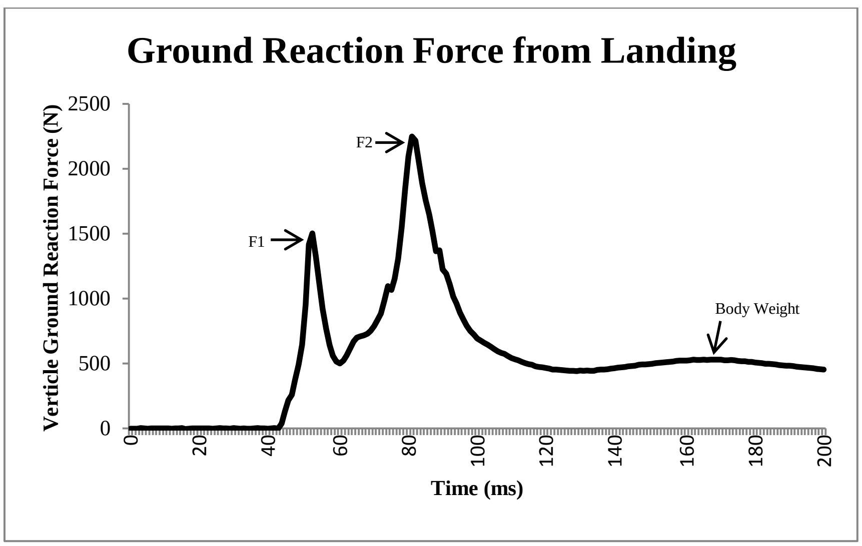

Figure 1.

Figure 1: Illustration of a typical Vertical Ground Reaction Force (GRF) during landing.

Dufek & Bates (1990), implemented a protocol that required three successful trials from three different heights, three different horizontal distances, and three different landing techniques to get a total of 81 trials. The three different landing techniques were classified by knee angle as stiff knee, slightly flexed knee, and fully flexed knee. All GRF data were normalized to body mass for comparative purposes. First (F1) and second (F2) maximum vertical forces (Figure 1) and the times to these were determined. Ankle, knee, and hip joint angles were calculated. An examination of the results led the authors to state that there is an importance in lower body kinematics on maximum vertical force. In the trials that subjects were told to land 'stiffly', F1 and F2 were greater than when landing 'softly'. The main characteristic of a 'stiff' landing was less knee flexion during the landing phase, 'softly' was increased knee flexion during the landing phase. Landing strategy was important in determining the ground reaction forces. As knee flexion increased at contact (fully flexed knee, slightly flexed knee, and stiff knee), F1 and F2 decreased for both independent variables of height and distance.

Examining this study explains the importance of lower extremity kinematics and how the body can lower the effect of the GRF on itself. By simply modifying one's landing technique (e.g., increasing knee flexion), overall impact force on the body can be lowered by 1-2 times body weight or even more (Dufek & Bates, 1990). However, it is important to understand that often athletes do not have the choice to modify landing style to reduce peak GRFs, such as successive jumps during a volleyball match.

In a study by DeVita & Skelly (1992), the researchers also evaluated landing stiffness (e.g., amount of knee flexion), but did so while observing joint kinetics in the lower extremity. While dropping from a distance above the floor, the subsequent landing will involve movements designed to dissipate the kinetic energy and will be characterized by work being performed on the muscles of the lower extremity. Work is defined as the effect of a force applied over some distance (Hamill, 2003). In this study, eight healthy female intercollegiate basketball and volleyball players were tested in single sessions and wore their own shoes. A force platform was used to measure vertical GRF. To standardize the vertical velocity during the descent phase, the subjects stepped off a 59 cm high platform that was placed 11 cm from the edge of the force platform. Each subject performed 10 successful trials for two conditions of soft and stiff landings. This study observed landing vertical GRF profiles similar to other studies where the impact phase ended in about 90 ms. During the impact phase, two force peaks were observed at approximately 15 and 53ms. Increased knee flexion during the landing phase, and lower vertical GRFs observed for the soft landings were in agreement with past research.

The ratio of muscular work parameter values at each joint to the summated work values across the three joints (hip, knee, and ankle) were used by DeVita & Skelly (1992), to identify the relative contributions of each muscle group to the landing performances. The summated muscular work values were -2.37 $J*kg^{-1}$ and -2.00 $J*kg^{-1}$ for soft and stiff landings, meaning the joints of the body were able absorb more kinetic energy during soft landing, reducing the impact stress placed on various structures in the body. The relative joint contributions to these totals were similar between conditions and were 25%, 37%, and 37% in soft and 20%, 31%, and 50% in stiff landings for the hip, knee, and ankle, respectively. The results indicated the ankle plantar flexors and knee extensors were the muscle groups primarily responsible for reducing the body's kinetic energy. Also, as landing stiffness increased, the relative contribution of the ankle plantar flexors increased while those of the hip and knee extensors decreased.

The results of DeVita & Skelly (1992) further cement the belief that soft landings (e.g., increased flexion during the landing phase) will aid to lower GRF, effectively lowering the amount of shock attenuation needed by the body. The results of this study allow the authors to specifically state what muscle groups performed more work to deal with the force applied on the body. Understanding the work the muscle groups are doing can help us understand which structures are under stress, mechanisms of injury, and how to better prevent injuries.

In a study by Hass et al. (2005), the researchers examined lower-extremity biomechanical differences between pre-pubescent and post-pubescent female recreational athletes during three drop landing sequences to determine whether maturation influenced injury risk. Sixteen recreational active post-pubescent women (18-25 years of age) and sixteen recreationally active girls (8-11 years of age) participated in the study. The authors concluded that there was a significant maturation level main effect for the GRF and joint forces. For example, pre-pubescent participants produced significantly greater peak F1 forces and reached peak F2 11 ms earlier than the post-pubescent group. The pre-pubescent participants displayed a lateral directed force at the knee that was significantly different than the medial directed force displayed by the post pubescent participants.

The mechanism of injury for ACL injury is internal rotation of the knee, and valgus force (medial force) (Bahr & Krosshaug, 2005; Ryder et al., 1997; Tillman, Hass, Brunt, & Bennett, 2004). The results of medially directed force in post pubescent participants, allows Hass et al. (2005) to suggest during development, something happens to women to give them a predisposition to ACL injury.

In a study by Self & Paine (2001), different types of landing techniques during jumping were evaluated. An understanding of landing techniques is important for the prevention of injuries in a number of athletic events. In this study, subjects were instructed to step off from a 12-inch high platform with four different landing conditions. The four different landing conditions consisted of, "The natural landing", whatever landing technique the subject would utilize in an actual sporting event, "Stick the landing", same drop but with minimal knee flexion, "Stick the landing and flex your calf muscles", same drop as before but making the landing soft by absorbing the impact through the toes and by flexing the calf muscles, and "Stick the landing but land more flat-footed", the same drop as before but not maximally flexing the calf muscles. For all drops, subjects were instructed to keep their hands above their head as to not affect recovery or balance. The results showed during natural landing the subjects obtained the least amount of ground reaction force and the greatest amount of knee flexion. The average minimum knee angles with knee bend were nearly 20° less than the three stiff-legged drops, indicating greater knee flexion for the bent knee drops. This kinematic response is the body's natural defense to guard against harmful ground reaction forces on the body. The results Self & Paine (2001) observed helps to understand how the body copes kinematically with forces applied to it.

Understanding the GRF applied to the body is a large step in understanding why injuries occur. If coaches and athletes know how to lessen the GRF and know where and how the body will absorb the force, then techniques and training can be administered to prevent foreseeable injuries from happening.

Shock Attenuation

Shock attenuation has been well studied in activities such as walking and running (Chu & Caldwell, 2004; Derrick, 2004; Dufek, Mercer, Teramoto, Mangus, & Freedman, 2008); Flynn, Holmes, & Andrews, 2004; Mercer, Devita, Derrick, & Bates, 2003; Mercer, Vance, Hreljac, & Hamill, 2002) however there is a paucity of research regarding shock attenuation and shock absorption in the event of landing. While the magnitude of the vertical component at impact in running is 3 to 5 times body weight, the vertical component in landing can be as much as 11 times body weight, depending on the height from which the person dropped (McNitt-Gray, 1989).

The aim of this section is to further understand stress placed on the body during landing. The forces that are imposed on the body due to landings must be attenuated primarily in the lower extremity (Coventry, O'Connor, Hart, Earl, & Ebersole, 2006). A common method used to examine shock reduction is to measure shock wave transmission from the lower extremity to the head using accelerometers (Derrick, 2004). Footwear (Brizuela, Llana, Ferrandis, & Garcia-Belenguer, 1997), muscles (Coventry et al., 2006), and overall composition of the body (Hass et al., 2005) aid in how the body handles the GRF. The question is to what severity certain anatomical structures bear the burden of the attenuated force.

In a study by Zhang et al. (2008), the researchers examined the impact of shock transmission and reduction in landing activities with varied mechanical demands. Ten active males were recruited for the study. They performed five successful step-off landing trials from each of five heights: 30, 45, 60, 75, 90cm. Kinematics of the right sagittal plane, GRF, and acceleration were recorded simultaneously. Impact frequencies were analyzed using a discrete Fast Fourier Transform and power spectral density was computed. The researchers reported increased range of motion for the ankle, knee, and hip joints at higher landing heights. The peaks of the vertical GRF, forehead and tibial accelerations, and eccentric muscle work by lower extremity joints were increased with increased landing heights. Shock reduction showed increased reduction at higher frequencies, but minimal changes across five landing heights. Unlike the responses observed for walking and running (Winslow & Shorten, 1989), the shock reduction did not show significant improvement with elevated mechanical demands. As the landing heights increased from 30 to 90 cm, the net joint eccentric work increased from 0.99 to 1.71 J/kg for the ankle plantar flexors, from 1.50 to 3.16 J/kg for the knee extensors, and from 0.99 to 2.84 J/kg for the hip extensors. The total amount of eccentric work performed by all lower extremity muscles also increased from 3.47 to 7.71 J/kg. The forehead and tibia accelerations demonstrated a small initial peak and a more significant second peak, which are associated with the forefoot and heel touchdown. Increases in the peak forehead acceleration were significant from 30 cm (2.18 g) to 90 cm (4.52 g) except for the comparisons between 30 cm and 45 cm, between 60 cm and 75 cm, and between 75 cm and 90 cm. Increases in the peak tibia acceleration were significant across all heights from 18.99 g to 60.05 g except for the changes between 30 cm and 45cm, between 45 cm and 60 cm, and between 75 cm and 90 cm.

The results that Zhang et al. (2008) obtained show a relationship between height and eccentric work performed in the muscles. The higher the drop the more work the muscles will do. The interesting observation is the decrease in acceleration magnitudes from head peaks to leg peaks. A limitation to understanding shock attenuation using these methods is that the magnitude of shock is measured at the leg and head levels. Using these methods, it is not clear if shock attenuation is being accomplished by the lower extremity or the trunk.

Zhang et al. (2008) presented that muscles definitely play a role in shock attenuation but were unable to determine how. In a study by Coventry et al. (2006), the researchers attempted to determine the effect of lower extremity fatigue on shock attenuation and joint mechanics during a single-leg drop landing. The researchers hypothesized that lower extremity fatigue would cause a decrease in the shock attenuation capacity of the musculoskeletal system during drop landings. Ten active male participants were recruited, eight used for analysis due to subject mortality. Each participant took part in a fatigue landing protocol. The protocol included cycles of a drop landing, a maximal countermovement jump, and five squats, repeated until exhaustion. Accelerometers were attached to the skin and tibia and head accelerations were measured. Lower extremity kinematics was collected using an electromagnetic tracking system and forces were measured using a force platform. The researchers observed that even though fatigue was induced, there was no significant change in shock attenuation throughout the body. Hip and knee flexion increased and ankle plantar flexion decreased at touchdown with fatigue. Hip joint work increased and ankle work decreased. The researchers concluded that the work distribution is thought to be a compensatory response to utilize the larger hip extensors that are better suited to absorb the mechanical energy of the impact. Their results suggested that the lower extremity is able to adapt to fatigue through altering kinematics at impact and redistributing work to larger proximal muscles.

Landing strategy changed as fatigue progressed in a way that maintained the same level of shock attenuation as fatigue became greater. This compensatory mechanism the body is displaying is quite interesting. It shows a type of recruitment of muscle to take the burden of the shock attenuation. The question that this mechanism brings to mind is does altering kinematics at impact predispose the fatigued individual to injury in sacrifice of the attenuation of the shock applied to the body.

The role of the muscle has been observed, and joints compensated to take the burden of the shock attenuation. In a study by Gross & Nelson, (1988), the role of the ankle during landing from a vertical jump was examined. Three levels of external surface cushioning were used to assess the hypothesized increased shock attenuation role of the ankle with increased damping demands. The objective was pursued with three measurement techniques. Collection of peak transient accelerations proximal and distal to the ankle with externally mounted low mass accelerometers , recording of resultant vertical force with a piezoelectric force platform, and measurement of ankle plantar flexion/dorsiflexion motion utilizing high speed cinematography. Eleven male recreational basketball players performed three symmetric barefoot countermovement vertical jumps on each surface. Peak acceleration at metatarsal contact varied little across landing surfaces. Across surfaces mean (Standard Deviations) peak accelerations of 20.8 (9.3) g and 14.3 (3.6) g were recorded at the calcaneus and tibia, respectively. Peak vertical force and ankle joint motion varied little across the surfaces, suggesting that the entrenched kinematics of landing surpassed the induced range of surface cushioning. Separation of the data by post-metatarsal contact landing style indicated that seven subjects landed with heel contact, with the remaining four attenuating the impact without heel contact. By avoiding the transient associated with the cessation of downward heel motion, the non-heel-contact-landers effectively reduced exposure to transients by nearly 50%.

Gross & Nelson (1988) hypothesized an increased shock attenuation role of the ankle with increased damping demands. They were unable to support their hypothesis with their conditions of landing surfaces, but they did notice discrepancies in landing technique that definitely played a role in shock attenuation. By landing “on the toes” and not having a heel-toe transfer at landing, subjects were able to greatly reduce the impact applied to the lower extremity.

Shock attenuation during landing has recently seen a flux of research being completed. Researchers manipulate the activity being studied, but still quantify shock attenuation the same way as total body shock attenuation. Dufek et al. (2008) studied the activity of running, but took a different approach to quantifying shock attenuation.

Dufek et al. increased running demands for female subjects, and measured shock attenuation to see if increased demands resulted in increased shock attenuation. The relevance to the Dufek et al. study on the current research is their instrumentation of the accelerometers. Dufek added a third accelerometer to the data collection. A third accelerometer was placed on the low back of subjects, in addition to the leg and head accelerometers, effectively dividing the body into two parts. This extra accelerometer allowed the researchers to quantify upper body and lower body shock attenuation, and not just rely on total body shock attenuation to understand how the body attenuations forces applied to it. Researchers studied three different groups of females, (pre-menarche, normally menstruating, post-menopausal). Lower extremity attenuation and variability were greatest for the pre-menarche group while impact variability was least for the normally menstruating group. Being able to study the body in two parts for shock attenuation, allows researchers to understand a bit more about where in the body shock attenuation happens.

There continues to be much research conducted in the area of shock attenuation, new ideas in regards to accelerometer attachment (Dufek, 2008), and more articles are being made available specifically in the area of shock attenuation in landing (Coventry et al., 2006; Decker et al., 2003; Derrick, 2004; Hass et al., 2005; Zhang et al., 2008). The question of the GRF causing a shock wave to transmit through the body and where is that shock wave being attenuated, is still a question without definite answers. Researchers have found various factors that play a role regarding shock attenuation, but one main key that stands out is the lower extremity kinematic relationship with shock attenuation. The body shows a kinematic compensation by increasing the angles of the ankle, knee and hip joints, which attenuates the force on the body. Technique, specifically altering kinematics, should be measured in various ways to determine concrete relationships between kinematics and shock attenuation. But before landing techniques and strategies can be fully understood, the location within the body that forces are primarily being attenuated should be investigated.

Summary of Literature Review

Jumping and subsequent landings are prevalent in many sports such as basketball and volleyball. In both running and jumping a force is applied to the body when the foot makes contact with the ground. The difference between running and jumping is the magnitude of that force applied to the body. In landing, the ground reaction force can be two to three times greater than that of running (McNitt-Gray, 2009).

Dufek & Bates (1990) examined different styles of landing to determine what effect landing style had on ground reaction force. They were able to conclude that specific knee kinematics during landing were able to lessen the amount of force applied to the body. Specifically a more bent knee approach to landing softened the impact the body had to overcome. This understanding of kinematics in landing can help to determine proper technique and instruction to be less susceptible to injury.

Researchers have found that the forces imposed on the body are primarily attenuated in the lower extremity (Coventry, O'Connor, Hart, Earl, & Ebersole, 2006). A common way to examine shock reduction is to measure shock wave transmission from the lower extremity to the head using accelerometers (Derrick, 2004). Though ground reaction force reduction can be achieved using increased knee flexion, we cannot say for certain the lower extremity is attenuating the bulk of the force without further investigation.

Zhang et al. (2008) examined the impact of shock transmission and reduction in landing activities with varied mechanical demands. Impact accelerations for the head significantly increased from the lowest (30 cm) landing height to the greatest (90 cm), but did not increase significantly incrementally from 30 cm to 45 cm, 45 cm to 60 cm, 60 cm to 75 cm, and 75 cm to 90 cm. However for tibial accelerations, all increments were significantly greater. Based of the results, the researchers determined that the lower extremity was responsible for the lack of increased demand at the head, even at greater heights. Based off of previous research in kinematics of landing and techniques, this is a safe assumption to make, however the data obtained in this study does not allow for the assumption. The researchers are measuring total body shock wave transmission thus they can only infer that the body is attenuating the shock somewhere, not a specific location.

Research in shock attenuation for landing and running is examined in this total body method. If the body was divided into two segments by adding an additional accelerometer attached somewhere in the midsection of the subjects, researchers could then determine if the shock is actually being attenuated in the lower extremity, or other structures such as the back and spine.

CHAPTER 3

METHODOLOGY

Subjects

Ten healthy adults (5-Male 5-Female, Age 26.3 ± 2.71 years, Height 1.68 ± 0.08 m, Mass 70.49 ± 16.03 kg), free from any current lower extremity injury that would interfere with the subject's ability to land, were recruited to be subjects in this study. Prior to volunteering for the research experiment, all subjects read and signed a University of Nevada, Las Vegas Institutional Review Board approved informed consent form.

Instrumentation

Ground reaction force was measured using a force platform (Kistler Instrument Corporation USA, Amherst, NY; Model #9281C [40 cm X 60 cm X 10 cm]), mounted flush with the floor in the middle of the biomechanics laboratory. Bi-lateral landings were performed with both feet contacting the force platform from a custom made stage that allowed for landing height to vary between 10 cm and 100 cm. The landing stage was positioned adjacent to the force platforms to minimize any horizontal displacement during the flight phase of landing. Leg, hip, and head accelerations were measured by securing three light weight uni-axial accelerometers (PCB Piezotronics, Depew, NY, model: 353C67, 6.7 grams, ±50-g range, frequency range = .5 Hz – 5 KHz) to the body. The sensitive axes of all accelerometers were aligned vertically with the subject in a standing position. All data were collected at 1008 Hz using Bioware (Kistler Instrument Corporation, Depew, NY; version 4.10) data acquisition software. Data collection was initiated 0.1 sec before contact and commenced after 0.5 sec had elapsed.

Experimental Protocol

Upon reporting to the laboratory and giving consent, subject age, height, and weight, were recorded. Subjects were given the option of a self-directed warm up. After warm up, an accelerometer was attached to the distal aspect of the right tibia on the medial side of the leg using a flexible elastic band and athletic tape. The accelerometer was fixed by tightening the strap to the subject's tolerance. The second accelerometer was attached to the right anterior superior iliac spine of the subject, using a nylon strap and athletic tape, similar to the procedure with the tibial attachment. The third accelerometer was mounted onto the anterior portion of a head-gear, similar to the inside of a hard-hat helmet (Figure 3). The head-gear was then placed on and tightened to the subjects head with the accelerometer flush to the forehead. Subjects were asked to stand at the edge of the stage and drop off with feet landing simultaneously on adjacent force platforms. The researcher then demonstrated the task the subject would be asked to do. All conditions consisted of the subject performing step off landings onto the force platform from the landing stage. Subjects completed five acceptable trials in each of three randomized conditions. Five trials were deemed satisfactory to account for overall fatigue during the landing activities (Zhang, 2008). A trial was successful if the subject stepped off and landed bilaterally with their both feet making contact completely within the border of the force platforms for no less than three seconds without falling way. Each subject completed three conditions. Each condition consisted of the same step off landing protocol, but at heights of 30 cm, 60 cm, and 90 cm respectively. The three heights were chosen because of previous results by Zhang (2008). Zhang tested at heights of 30 cm, 45 cm, 60 cm, 75 cm, and 90 cm with linear impact peak results increasing with height. Therefore it was deemed for this study, that the intermediate heights of 45 cm and 75 cm were unnecessary.

Data Reduction

All data were reduced using a custom laboratory program (Matlab, version info will be in appendix) written for this study. Peak impact accelerations were identified for the leg, hip, and head respectively. The acceleration measurements from the leg, hip, and head accelerometers were expressed in multiples of gravitational acceleration (g). After peak impact accelerations were identified, total body SA was calculated by using the formula "[1-(PkHead/PkLeg)]*100", lower body SA was calculated using the formula "[1-(PkHip/PkLeg)]*100", and upper body SA was calculated using the formula "[1-(PkHead/PkHip)]*100".

Statistical Analysis

Two dependent variables were analyzed: 1) Impact acceleration and 2) Shock Attenuation. There were two independent variables for Impact Acceleration: Location (three levels: leg, hip, and head) and height (three levels: 30 cm, 60 cm, 90 cm). For SA, there were two independent variables: location (three levels: total body SA, lower body SA, and upper body SA) and height (three levels: 30 cm, 60 cm, and 90 cm). Repeated measures ANOVAs were used to compare each dependent variable between landing conditions. When the results of the repeated measures revealed significant differences, pairwise comparisons were made to determine where the differences occurred. All statistical tests were conducted using Statistical Package for the Social Sciences (SPSS Inc, Chicago, IL; version 17.0).

CHAPTER 4

RESULTS

Impact Peak Accelerations

Table 1 illustrates means and standard deviations for impact peak accelerations. There was an interaction effect between height and location (*$p<0.05$*). Specifically Leg impact peak accelerations increased across heights of 30 cm to 60 cm (*$p<0.05$*) and 30 cm to 90 cm (*$p<0.05$*) with an overall increase of 37.99 (10.65) g across the 30 cm to 90 cm height conditions. Hip impact peak accelerations increased across heights of 30 cm to 60 cm (*$p<0.05$*) and 30 cm to 90 cm (*$p<0.05$*) with an overall increase of 3.48 (1.25) g across the 30 cm to 90 cm height conditions. Head impact peak accelerations increased across heights of 30 cm to 60 cm (*$p<0.05$*) and 30 cm to 90 cm (*$p<0.05$*) with an overall increase of 1.93 (0.80) g across the 0 cm to 90 cm height conditions.

Table 1 Mean and standard deviations for impact peak accelerations across heights of 30, 60, and 90 cm

	Heights		
	30 cm	60 cm	90 cm
Leg (g)	21.97 (6.16)	50.22 (21.60)	59.96 (16.81)
Hip (g)	5.70 (1.70)	8.29 (3.28)	9.18 (2.95)
Head (g)	3.23 (1.38)	4.70 (2.07)	5.15 (2.08)

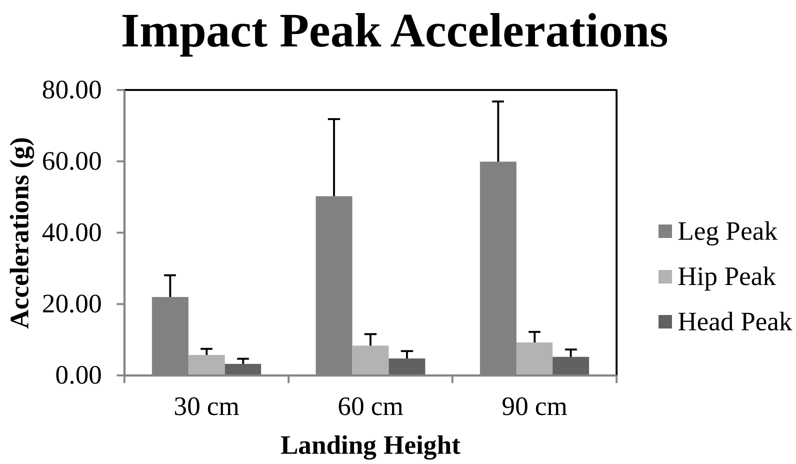

Fig. 2. Mean impact peak accelerations of the Leg, Hip, and Head at landing heights 30 cm, 60 cm, and 90 cm. Each parameter illustrated is represented by the mean and standard deviation of 10 subjects at each height.

Shock Attenuation

Table 2 illustrates means and standard deviations for shock attenuation. There was not an interaction effect between height and location ($p>0.05$). Shock attenuation was influenced by height ($p<0.05$) but not location ($p>0.05$). Specifically total body SA did not change from heights of 30 cm to 60 cm ($p>0.05$) but increased from heights of 30 cm to 90 cm ($p<0.05$). Lower body SA increased from heights of 30 cm to 60 cm ($p<0.05$) and 30 cm to 90 cm ($p<0.05$). Upper body SA saw no change from heights of 30 cm to 60 cm ($p>0.05$) and 30 cm to 90 cm ($p>0.05$).

Table 2 Mean and standard deviations for SA across heights of 30, 60, and 90 cm

	Heights		
	30 cm	60 cm	90 cm
Total SA (%)	83.99 (6.42)	87.16 (8.95)	90.19 (5.13)
Lower body SA (%)	72.23 (8.32)	78.23 (8.32)	82.66 (7.52)
Upper body SA (%)	44.27 (11.30)	44.30 (14.65)	44.28 (13.82)

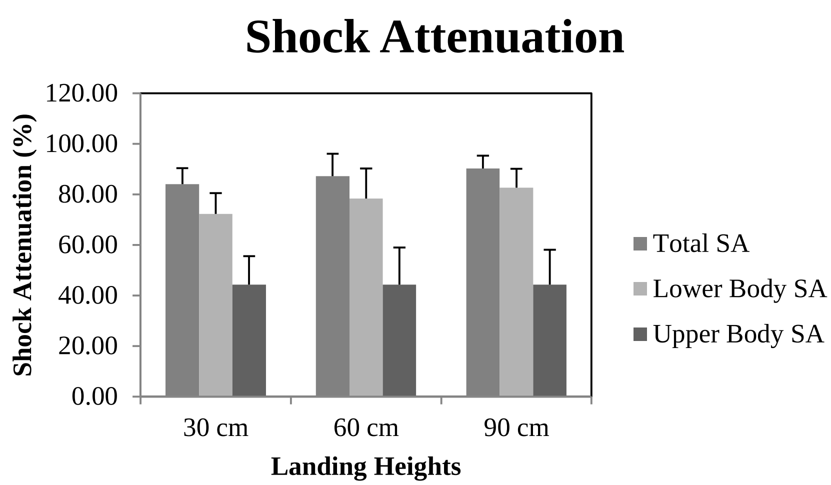

Fig. 3. Total, lower body, and upper body shock attenuations at landing heights 30 cm, 60 cm, and 90 cm. Each parameter illustrated is represented by the mean and standard deviation of 10 subjects at each height.

CHAPTER 5

SUMMARY, CONCLUSIONS,

AND RECOMMENDATIONS

Discussion of Results

The purpose of this study was to determine SA characteristics between different segments while landing from varied heights. Specifically, the unique aspect of this study was that SA was examined between leg-hip (Lower Body SA), hip-head (Upper Body SA), as well as leg-head (Total Body SA) locations. Furthermore, impact characteristics during landing from different heights were measured and examined in order to understand SA parameters. An increase in lower body shock attenuation across conditions of height, but not in upper body shock attenuation, gives evidence that the lower body is attenuating the shock from landing. The hypotheses that 1) Hip peak impact acceleration is influenced by height of landing, 2) Leg peak impact acceleration is influenced by height of landing, 3) Head peak impact acceleration is influenced by height of landing, 4) Lower body SA will be greater than upper body SA at each height, 5) Total body SA is influenced by height of landing, are all tenable.

Previous research has been conducted on impact accelerations and shock transmission during increased landing demands (Zhang et al., 2008). In that study, it was reported that with increased landing demands, impact peak accelerations increased, but shock transmission did not increase as the landing demand increased (Zhang et al., 2008).

The results of the present experiment are in agreement with the increased impact peak accelerations during landing. In contrast, in the present study SA increased across heights. Both studies used the same minimum and maximum heights, as well as accelerometer attachment of the head and leg, therefore differing results for total body shock attenuation/transmission is unexplained.

Leg peak accelerations increased on average 37.98 g (273%) from heights 30 cm to 90 cm. Hip peak accelerations increased 3.48 g (161%) from heights 30 cm to 90 cm. Head peak accelerations increased 1.92 g (158%) from heights 30 cm to 90 cm. Clearly, leg peak accelerations had the greatest magnitude and percentage increase. All three sites had an increase in peak acceleration with an increase in height. The observation of greater magnitude of acceleration and greater change of acceleration at the leg level vs. hip or head seems to suggest that the lower extremity is attenuating a majority of the shock. The observation that hip and head peak accelerations were similar to each other and between heights, interrelated to a lack in change of total body shock attenuation is also evidence that the lower extremity is attenuating the shock from landing.

Previous research demonstrated that there is a relationship between increased speed demands in running and shock attenuation (Dufek et al., 2008, Mercer et al., 2002). In the present study, as impact demands increased with increased heights, shock attenuation increased as well. Total body shock attenuation increased from 83.99% to 90.19% from heights of 30 cm to 90 cm. Upper body shock attenuation experienced no change across all landing heights. Lower body shock attenuation increased from 72.23%

to 82.66% from heights of 30 cm to 90 cm. Lower body shock attenuation between heights of 30 cm (72.23%) and 60 cm (78.33%) was significantly different. With the increase of total body and lower body shock attenuation, but no increase in upper body shock attenuation, again the results suggest the lower extremity is doing more work to absorb impact energy. Future research in this area should target injury specific questions with regard to the lower extremity and landing.

A confounding factor to this study was that participants could have lacked experience in landing technique. Participants were not screened for previous experience levels (i.e.: collegiate volleyball or basketball player). This potential confounding factor was accounted for by giving detailed instruction and demonstration of the step-off and landing techniques as well as time to become acclimated to the activity. A confounding factor to this study was that participants could have experienced fatigue, contributing to skewed results. To account for fatigue during the study, condition order was randomized and participants were given sufficient time to rest between trials. Another confounding factor to this study was that heights were randomized. In previous research heights were ordered successively. If order of heights was controlled in a successive manner, then results for this study may have had a different outcome. However, after piloting different orders of landings, there seemed to be no causation to believe that order would affect the outcome at all.

Limitations of this study were that lower extremity kinematics were not collected to quantify possible explanations for the difference in impact peak accelerations for the leg, hip, and head. Gender differences also were not accounted for.

Conclusions and Recommendations
For Further Study

In conclusion, this study was designed to better understand the mechanisms of shock attenuation during the event of landing. With an increase in landing height, it was concluded that impact peak accelerations of the lower extremity would also increase. Though impact peak of the lower extremity increased, total body shock attenuation had no change between successive heights, and little change across total height. A possible explanation for the lack of change in total body shock attenuation is that the lower extremity is attenuating the initial impact peak acceleration. The results of this study provide possible new ways to evaluate shock attenuation, focusing on the lower extremity. The idea that the lower extremity is of greater importance in attenuating an impact shock also has benefits for training and coaching for sports that involve jumping and landing movements.

APPENDIX I

Custom Data Processing Programs

Main Program

thesisSAprogram.m

```
%thesissaprog.m

%This program calculates leg, hip, and head acc, as well as total, lower,

%and upper SA

clc

clear;

clear all;

fclose('all');

fprintf(1,'\n\nProcessing\n\n');

%============================================================

%       Change the following parameters

%       prior to running program

%============================================================

subjects        = 10 ; %number of subjects to process

conditions      = 3 ; %number of conditions per subject

trials          = 5 ; %number of trials per condition

startwithsubj   = 1 ; %subject number to start with
```

```
startwithcond   = 1 ; %condition number to start with

startwithtrial  = 1 ; %trial number to start with


directory       = 'c:\biomech\data\'; %directory where data is located

extension       = '.txt';

outputfile      = 'alldata';

searchwindow    = 25

npeaks          = 1

precision       = 4; %output precision


savedata        = 'yes';

savefiles       = 'no';


%============================================================

%Don't change after this point

%============================================================


bioheaders      = 13;

biofs           = 1008;

biocol          = 5;
```

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

alldata = [];
filenumber = 0;

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

      %create filename
      ss = int2str(s);
      cc = int2str(c);
      tt = int2str(t);
      filename = ['s' ss 'c' cc 't' tt extension];

      %counter
      filenumber = filenumber+1;

      %open a file
      biodata = my_fopen('c:\biomech\data', filename, biocol, inf, bioheaders);
```

```
%assign variables from bioware

heada       = biodata(:,3);

lega        = biodata(:,4);

hipa        = biodata(:,5);

biotime     = biodata(:,1);


%identify leg acc, hip acc, head acc, SA


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


subplot(2,1,1)

plot(biotime,lega, 'k');

hold on

ylabel('leg acceleration (g)')

xlabel('time(s)')

title('Leg Acceleration While Landing')


%find peaks

numberofpeaks = 1

fprintf(1,'\n');
```

```
for i = 1:numberofpeaks

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

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

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

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

    legpeak(i)  = max(lega(start:xpos+searchwindow));
```

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

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

end
pause (0.5)
close(gcf)
figure('position', [100 80 1000 400])

subplot(2,1,1)
plot(biotime,hipa, 'k');
hold on
ylabel('hip acceleration (g)')
xlabel('time(s)')
title('Hip Acceleration While Landing')

%find peaks
```

```
numberofpeaks = 1
fprintf(1,'\n');

for i = 1:numberofpeaks

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

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

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

    if (endsearch>length(hipa))
        endsearch = length(hipa);
    end
```

```
    hippeak(i)  = max(hipa(start:xpos+searchwindow));
    temppeakpos = find(hipa(start:xpos+searchwindow)==hippeak(i));
    temppeakpos(2) = 0;
    peakpos(i)  = temppeakpos(1);
    peakpos(i)  = peakpos(i) + (start)-1;

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

end
pause (0.5)
close(gcf)

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

subplot(2,1,1)
plot(biotime,heada, 'k');
hold on
ylabel('head acceleration (g)')
xlabel('time(s)')
```

```
title('Head Acceleration While Landing')

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

for i = 1:numberofpeaks

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

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

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

```
    if (endsearch>length(heada))
        endsearch = length(heada);
    end

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

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

end
pause (0.5)
close(gcf)

%Calculate shock attenuation

%Total Body SA
fprintf(1,'\n\nTotal Body Shock Attenuation Calculated.\n\n')
```

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

%Lower Body SA

fprintf(1,'\n\nLower Body Shock Attenuation Calculated.\n\n')

    lbsa = (1-hippeak(i)/legpeak(i))*100;

%Upper Body SA

fprintf(1,'\n\nUpper Body Shock Attenuation Calculated.\n\n')

    ubsa = (1-headpeak(i)/hippeak(i))*100;

%compile the data for each loop
                Thesisdata(filenumber, :) = [s c t legpeak hippeak headpeak tbsa
lbsa ubsa];

clear biodata;
```

```
        end
    end
end

my_save(directory, outputfile, Thesisdata, 4);

fprintf(1,'\nDone Processing\n\n')
```

Supporting Programs

my_Fopen.m

```
%function:  my_fopen
%this function will run the commonly used commands to open a file.
%
%called as:
%       data = my_fopen(directory, filename, columns, rows, headers)
%
%where
%       directory       = location of file
%       filename        = name of file with extension
```

```
%	columns			= number of columns
%	rows		= number of rows
%	headers			= number of headers to get rid of

function tempdata = my_fopen(my_dir, file__name, columns, rows, headers);

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

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

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

	%create filename
```

```
file_name = [c, file__name, d];

%open peak input file
   eval(file_name);

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

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

   %read in data
```

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



%close files
fclose('all');
```

my_save.m

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

        %initialize variable
        all_column_info = [];

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

        %open the file to write to
```

```
        fid=fopen(filename, 'w');

%make quote notation
        q='"';

%check the size of the data array
        [rows columns] = size(data);
%Create the necessary write commands

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

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

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

%create command line
```

```
print_command = ['fprintf(fid,' q all_column_info '\n' q ', data);'];

%save data
    eval([print_command]);

%close file
    fclose(fid);

%change back to original directory
    eval(['cd ' temp]);
```

APPENDIX II

Statistical Tables

Data Sets per Subject

Peak Impact Accelerations

Table 3. Subject peak impact acceleration means for 30 cm, 60 cm, and 90 cm landing height. LgPk = Leg Peak Impact Acceleration, HpPk = Hip Peak Impact Acceleration, HdPk = Head Peak Impact Acceleration

	LgPk_30 cm	LgPk_60 cm	LgPk_90 cm	HpPk_30 cm	HpPk_60 cm	HpPk_90 cm	HdPk_30 cm	HdPk_60 cm	HdPk_90 cm
S1	14.14	38.54	47.63	4.92	7.08	8.87	2.66	4.62	4.47
S2	20.70	28.12	41.27	7.08	9.13	10.09	4.62	6.33	6.02
S3	17.80	40.77	53.65	4.96	6.05	6.86	2.48	4.03	5.25
S4	28.31	78.49	98.97	9.14	15.70	10.12	5.11	6.87	6.73
S5	16.63	22.38	61.36	5.86	8.98	13.95	3.56	5.72	6.87
S6	21.04	35.86	44.67	6.66	11.25	13.37	4.14	7.91	8.14
S7	27.57	84.42	61.82	6.55	7.11	6.42	4.72	4.01	1.98
S8	18.24	69.41	72.35	3.99	7.89	10.38	1.56	4.16	6.26
S9	21.44	61.00	65.45	3.64	4.68	5.65	1.48	1.16	2.03
S10	33.86	43.23	52.40	4.18	5.03	6.08	1.95	2.21	3.69
Avg	21.97	50.22	59.96	5.70	8.29	9.18	3.23	4.70	5.15
Std	6.12	21.60	16.81	1.70	3.28	2.95	1.38	2.07	2.08

Data Sets per Subject

Shock Attenuation

Table 4. Subject Shock Attenuation means for 30 cm, 60 cm, and 90 cm landing height. TBSA = Total-body Shock Attenuation, LBSA = Lower-body Shock Attenuation, UBSA = Upper-body Shock Attenuation

	TBSA 30 cm	TBSA 60 cm	TBSA 90 cm	LBSA 30 cm	LBSA 60 cm	LBSA 90 cm	UBSA 30 cm	UBSA 60 cm	UBSA 90 cm
S1	80.73	84.79	90.32	64.14	76.36	80.74	45.36	35.14	48.38
S2	76.82	76.77	84.75	70.69	65.24	74.56	24.48	30.61	40.29
S3	83.69	86.19	89.92	67.18	78.28	85.71	49.93	31.50	25.40
S4	81.69	91.10	93.20	65.87	79.63	89.80	44.62	55.94	33.42
S5	77.78	72.85	86.55	63.18	56.99	75.75	38.79	36.16	49.53
S6	80.19	77.52	80.19	67.99	67.70	68.47	37.12	30.42	35.36
S7	80.46	94.58	95.66	74.75	90.63	86.69	32.13	44.33	69.18
S8	91.56	94.08	91.24	78.16	87.92	85.15	58.57	48.20	40.58
S9	92.77	98.14	96.89	82.59	92.19	91.36	59.25	75.39	64.44
S10	94.16	95.53	93.19	87.73	88.31	88.35	52.45	55.31	36.24
Avg	83.99	87.16	90.19	72.23	78.33	82.66	44.27	44.30	44.28
Std	6.42	8.95	5.13	8.32	11.93	7.52	11.30	14.65	13.82

Tests of Within Subject Effects

Peak Impact Accelerations

Table 5. Tests of Within Subjects Effects for Peak Impact Accelerations

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
height	Sphericity Assumed	29066.995	2	14533.498	85.905	.000	.905	171.809	1.000
	Greenhouse-Geisser	29066.995	1.007	28869.733	85.905	.000	.905	86.491	1.000
	Huynh-Feldt	29066.995	1.009	28796.219	85.905	.000	.905	86.712	1.000
	Lower-bound	29066.995	1.000	29066.995	85.905	.000	.905	85.905	1.000
Error(height)	Sphericity Assumed	3045.276	18	169.182					
	Greenhouse-Geisser	3045.276	9.061	336.068					
	Huynh-Feldt	3045.276	9.085	335.212					
	Lower-bound	3045.276	9.000	338.364					
location	Sphericity Assumed	3387.349	2	1693.674	31.758	.000	.779	63.516	1.000
	Greenhouse-Geisser	3387.349	1.910	1773.686	31.758	.000	.779	60.651	1.000
	Huynh-Feldt	3387.349	2.000	1693.674	31.758	.000	.779	63.516	1.000
	Lower-bound	3387.349	1.000	3387.349	31.758	.000	.779	31.758	.999
Error(location)	Sphericity Assumed	959.947	18	53.330					
	Greenhouse-Geisser	959.947	17.188	55.850					
	Huynh-Feldt	959.947	18.000	53.330					
	Lower-bound	959.947	9.000	106.661					
height * location	Sphericity Assumed	4483.550	4	1120.887	22.944	.000	.718	91.777	1.000
	Greenhouse-Geisser	4483.550	1.797	2494.905	22.944	.000	.718	41.233	1.000
	Huynh-Feldt	4483.550	2.217	2022.103	22.944	.000	.718	50.874	1.000
	Lower-bound	4483.550	1.000	4483.550	22.944	.001	.718	22.944	.989
Error(height*location)	Sphericity Assumed	1758.687	36	48.852					
	Greenhouse-Geisser	1758.687	16.174	108.737					
	Huynh-Feldt	1758.687	19.955	88.131					
	Lower-bound	1758.687	9.000	195.410					

a. Computed using alpha = .05

Tests of Within Subject Effects

Shock Attenuation

Table 6. Tests of Within Subject Effects for Shock Attenuation

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
height	Sphericity Assumed	30410.673	2	15205.336	375.833	.000	.977	751.665	1.000
	Greenhouse-Geisser	30410.673	1.235	24630.357	375.833	.000	.977	464.034	1.000
	Huynh-Feldt	30410.673	1.332	22823.282	375.833	.000	.977	500.775	1.000
	Lower-bound	30410.673	1.000	30410.673	375.833	.000	.977	375.833	1.000
Error(height)	Sphericity Assumed	728.239	18	40.458					
	Greenhouse-Geisser	728.239	11.112	65.535					
	Huynh-Feldt	728.239	11.992	60.727					
	Lower-bound	728.239	9.000	80.915					
location	Sphericity Assumed	464.010	2	232.005	2.877	.082	.242	5.754	.492
	Greenhouse-Geisser	464.010	1.885	246.218	2.877	.086	.242	5.421	.475
	Huynh-Feldt	464.010	2.000	232.005	2.877	.082	.242	5.754	.492
	Lower-bound	464.010	1.000	464.010	2.877	.124	.242	2.877	.329
Error(location)	Sphericity Assumed	1451.651	18	80.647					
	Greenhouse-Geisser	1451.651	16.961	85.588					
	Huynh-Feldt	1451.651	18.000	80.647					
	Lower-bound	1451.651	9.000	161.295					
height * location	Sphericity Assumed	277.747	4	69.437	1.677	.177	.157	6.709	.463
	Greenhouse-Geisser	277.747	1.674	165.932	1.677	.221	.157	2.807	.277
	Huynh-Feldt	277.747	2.012	138.060	1.677	.215	.157	3.374	.307
	Lower-bound	277.747	1.000	277.747	1.677	.228	.157	1.677	.213
Error(height*location)	Sphericity Assumed	1490.479	36	41.402					
	Greenhouse-Geisser	1490.479	15.065	98.938					
	Huynh-Feldt	1490.479	18.106	82.319					
	Lower-bound	1490.479	9.000	165.609					

a. Computed using alpha = .05

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