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Effectiveness of Spinal Unloading Positions in Recovering From Spinal Shrinkage Incurred While Running

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EFFECTIVENESS OF SPINAL UNLOADING POSITIONS IN RECOVERING FROM SPINAL SHRINKAGE INCURRED WHILE RUNNING

A Thesis

Presented to

Eastern Washington University

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In Partial Fulfillment of the Requirements

For the Degree

Master of Science

In Physical Education

By,

Jennifer E. Kumanchik

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THESIS OF JENNIFER E. KUMANCHIK APPROVED BY

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MASTER'S THESIS

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Chapter 1

Introduction

Running USA (2013) reports approximately 51.4 million Americans participated in recreational running in the 2012 calendar year. Annual participation rates over the past decade have increased 9% and are anticipated to increase 7.3% percent in the future (Running USA, 2012). It is estimated 10% of novice recreational runners experience lumbar pain or injury, contributing to high rates of attrition within the first year of training (Taunton, Ryan, Clement, Mckenzie, Lloyd-Smith, & Zumbo, 2003). Running exposes the body to repetitive application of compressive force equivalent to 2-4 times the body weight with every foot strike, called ground reaction force (GRF) (Cavanaugh, 1990; Novacheck, 1997). Although the vertebral column is capable of withstanding significant amounts of compressive force while performing dynamic motion, once defined thresholds are exceeded, permanent damage may occur (Broberg, 1993; Nachemson, 1976; Sward, Hellstrom, & Jacobsson, 1990; White & Panjabi, 1990). Sward et al. (1990) assessed degenerative effects of GRF on the spine and reported levels of intervertebral disc degeneration at 75% among experienced runners compared to 31% among non-runners. With continued rapid growth of recreational running and the long-term health implications upon the spine, it is necessary to explore potential methods of reducing the occurrence of lumbar pain/injury resulting from running.

As compressive force is absorbed within the spine, fluid is expelled from the intervertebral disc (IVD), resulting in deformation of disc shape and reduction of space between the vertebral bodies (Broberg, 1993; Haher, O'Brien, Kauffman, & Liao, 1993; Hirsch, 1955; Nachemson, 1976; Roaf, 1960; White & Panjabi, 1990). Although this spinal shrinkage occurs naturally as a result of circadian variation and activities of daily living, this process becomes accelerated with the performance of dynamic motion (Broberg, 1993; Nachemson, 1976; Tyrell, Reilly, & Troup, 1985; Van Deursen, Van Deursen, Snijders, & Wilke, 2005; Wilby, Linge, Reilly, & Troup, 2005). Research suggests a correlation between applications of acute, short duration compressive force and occurrence of catastrophic spinal injury within high-impact sports such as football, gymnastics, and rugby (Bohu et al., 2009; Haher et al., 1993; Nachemson, 1976; Reilly, 2010; White & Panjabi, 1990). Nonetheless, chronic applications of low magnitude compressive force have been correlated with the occurrence of degenerative injury to IVDs within endurance sports such as running (Broberg, 1993; Nachemson, 1976; Reilly, 2010; Roaf, 1960; Sward et al., 1990; White & Panjabi, 1990). Ground reaction forces experienced while running expose the spine to repetitive applications of low magnitude force (Cavanaugh, 1990; Nachemson, 1990; Novacheck, 1997). However, variation in running mechanics and techniques including speed, intensity, and stride length influence the amount of GRF absorbed (Dowzer, Reilly, & Cable, 1998; Garbutt, Boocock, Reilly, & Troup, 1989; Kingsley, D'Silva, Jennings, Humphries, Dalbo, & Scanlan, 2012; Roush, Schlicht, & Flannagan, 2004). Measuring changes in overall stature and

IVD height have been used to assess the effects of GRF on the spine (Carrigg & Hillemeyer, 1992; Dmitriadis et al., 2011; Dowzer et al., 1998; Fowler, Rodacki, & Rodacki, 2005; Garbutt, Boocock, Reilly, & Troup, 1990; Kingsley et al., 2012; Leatt, Reilly, & Troup, 1986; Reilly, 2010; Roush et al., 2004; Seay, Selbie, & Hamill, 2008; White & Malone, 1990). These results have identified compressive force as a probable mechanism for lumbar pain and injury (Garbutt et al., 1989; Sward et al., 1990; White & Panjabi, 1990). Limited research has focused upon methods, such as spinal unloading, to recover from the effects of compressive force.

Spinal unloading techniques involve reducing the effects of gravity by manipulating the position of the body, thus promoting elongation of the spine (Garbutt et al., 1990). Isolated assessments demonstrate various standing, seated, inverted, and supine positions effectively reduce spinal shrinkage. Inverted and supine positions yield greater immediate benefits than standing or seated positions (Fowler, Lees, & Reilly, 1994; Fowler et al., 2005; Gerke, Brismee, Sizer, Dedrick, & James, 2011; Healey, Fowler, Burden, & McEwan, 2004; Rodacki, Fowler, & Rodacki, 2003; Rodacki, Rodacki, Ugrinowitsch, Zielinski, & Budal da Costa, 2007). Currently only two studies have compared the effectiveness of multiple positions (Gerke et al., 2011; Healey et al., 2004). Limited analysis of these positions has followed the conclusion of dynamic activity (Healey et al., 2004). Research assessing effects of GRF on stature and IVD height due to running employed a spinal unloading technique before experimental protocol to control for stature loss due to circadian variation and activities of daily living (Ahrens, 1994; Carigg & Hillemeyer, 1992; Dowzer et al., 1998; Garbutt et al., 1990; Kinglsey et al., 2012; Leatt et al., 1986; Seay et al., 2008). Others control for this potential variation in stature by completing all experimental protocol within the same time frame each day (Dmitriadis et al., 2011; Roush et al., 2004; White & Malone, 1990). Only two studies have assessed the effectiveness of these positions in immediately recovering from the effects of GRF on stature and IVD height by employing an unloading position before and after experimental protocol (Dowzer et al., 1998; Garbutt et al., 1990). Similarly, these assessments included only one position. Currently, no study has assessed the effectiveness of multiple unloading positions in immediately recovering from the compressive effects of GRF on stature and IVD height induced while running.

Statement of the Problem

Running inevitably exposes the body to repetitive application of compressive force (Cavanaugh et al., 1980; Novacheck, 1997). This recurring application stresses the structural integrity of the IVD, progressively reducing its ability to withstand compressive loading and increasing the likelihood of experiencing an injury (Broberg, 1993; Haher et al., 1993; Hirsch, 1955; Roaf, 1960; Reilly, 2010; Sward et al., 1990; White & Panjabi, 1990). Prior research demonstrates that running results in significant changes in stature and IVD height; however there is limited focus on potential recovery techniques (Carrigg & Hillemeyer, 1992; Dmitriadis et al., 2011; Dowzer et al., 1998; Fowler et al., 2005; Garbutt et al., 1990; Kinglsey et al., 2012; Leatt et al., 1986; Reilly, 2010; Roush et al., 2004; Seay et al., 2008; White & Malone, 1990). Spinal unloading research has revealed beneficial results concerning the potential of different body positions in recovering from spinal shrinkage. Two studies have compared the effectiveness of multiple positions; however, only one involved assessment following a dynamic activity (Gerke et al., 2011; Healey et al., 2004). No study has assessed the immediate effectiveness of multiple positions in recovering from the effects of compressive forces induced while running. Therefore, the purpose of this study was to assess the immediate effectiveness of four different spinal unloading positions in recovering from lumbar spinal shrinkage incurred while running among recreational runners. This research sought to determine if a significant difference would occur between four different supine position conditions: Fowler position, side lying with spinal flexion, supine with lumbar support, and supine with no support.

Hypothesis

It was hypothesized that there would be no significant difference in the recovery of IVD height and stature between four spinal unloading position conditions among a group of recreational runners. The dependent variables for the study were change in IVD height (cm) and seated stature (mm) measurements. The independent variables included four levels of supine spinal unloading positions: Fowler position, side lying with spinal flexion, supine with lumbar support, and supine with no support.

Delimitations, Limitations, and Assumptions

Previous research analyzing the effects of compressive forces on IVDs when running have primarily used elite or competitive male runners (Ahrens, 1994; Carrigg & Hillemeyer, 1992; Garbutt et al., 1990; Leatt et al., 1986; Roush et al., 2004; White & Malone, 1990). This study was delimited to the use of a convenience sample composed of male and female recreational runners. This sample was sought from students at Eastern Washington University in Cheney, Washington; therefore results may be limited in their application and may not reflect the potential effects of age and experience of the runner.

To control for intra-participant variability, attire was delimited to wearing the same footwear during each experimental session. Inter-participant variability still occurred due to the inability to control for all participants wearing the same brand and model of footwear and mechanics such as foot strike patterns. These limitations may have influenced the amount of GRF and IVD shrinkage experienced by the runner. It was assumed that participants did not engage in activities beyond those of daily living on days engaging in experimental protocol. Participants were notified of this requirement through verbal instruction during the familiarization day.

The experimental protocol for this study was delimited to participants performing a single 15 min interval run with 5 min warm-up per experimental session. Previous experimental protocols involved participants completing two, 15 min interval runs (Dowzer et al., 1997; Garbutt et al., 1989; Kinglsey et al., 2012; White & Malone, 1990). Results consistently demonstrated that the greatest amount of shrinkage occurs within the first 15 min interval run, with little to no shrinkage occurring within the second 15 min interval run (Dowzer et al., 1997; Garbutt et al., 1989; Kingsley et al., 2012; Roush et al., 2004; White & Malone, 1990). Running surface and incline can influence the amount of GRF experienced by a runner (Cavanaugh et al., 1980; Novacheck, 1997). Therefore, this study was delimited to all running being completed on a Trackmaster TMX425C™ motorized treadmill at an incline of 0° and constant speed. The Karvonen formula was used to calculate, monitor, and maintain the intensity at which each participant was running (Karvonen & Vuorimaa, 1988). The results from this study may not reflect the variation of GRF and IVD shrinkage incurred while running associated with differing surfaces, incline, or athlete mechanics.

The effectiveness of multiple standing, seated, inverted, and supine unloading positions have been assessed, with supine and inverted positions yielding the greatest immediate benefits in recovering from spinal shrinkage when compared to standing or seated positions (Fowler et al., 1994; Fowler et al., 2005; Gerke et al., 2011; Healey et al., 2004; Rodacki et al., 2003; Rodacki et al., 2007). Assessments for this study were delimited to supine unloading positions.

Preceding studies have measured spinal shrinkage incurred while running by measuring changes in overall stature and IVD height (Carigg & Hillemeyer, 1992; Dmitriadis et al., 2011; Dowzer et al., 1998; Fowler et al., 2005; Garbutt et al., 1990; Kinglsey et al., 2012; Leatt et al., 1986; Reilly, 2010; Roush et al., 2004; Seay et al., 2008; White & Malone, 1990). A stadiometer, as originally described by Boocock, Reilly, Linge, and Troup (1986), was the standard measurement tool used for change in stature. Radiographic imaging including magnetic resonance imaging (MRI), computerized tomography (CT), and diagnostic ultrasound have become the standard methods of measurement for changes in IVD height (Carigg & Hillemeyer, 1992; Dmitriadis et al., 2011; Kadziolka, Aszately, Hanai, Hansson, & Nachemson, 1981; Kinglsey et al., 2012; Ledsome, Lessoway, Susak, Gagnon, & Wing, 1996; Naish, Mitchell, Innes, Halliwell, & McNally, 2003; Shao, Rompe, & Schiltenwolf, 2002). Due to lack of access to these devices, measurement protocol for this study was delimited to the use of a Harpenden© sliding anthropometer for seated stature and Sonosite© Micromaxx™ diagnostic ultrasound with C60E/5-2 MHz™ transducer for IVD height. Although several studies have validated the precision of diagnostic ultrasound as a method for measuring IVD height, results are limited to the changes in distance between transverse processes of the vertebral bodies instead of direct imaging of the IVD. Ultrasound imaging was delimited within the fifth lumbar and first sacral intervertebral disc space region where the spine absorbs the greatest amount of force (Cavanaugh et al., 1980; Nachemson, 1976; Novacheck, 1997; White & Panjabi, 1990). All stature measurements occurred with the participant in a seated position, resting against a rigid wooden frame for postural control. This may limit the results of this study to only assessing shrinkage of only the spine through seated height measurement change and not change in overall stature.

Significance

The spine endures compressive forces 2-4 times the body weight of an individual when running (Cavanaugh et al., 1980; Novacheck, 1997). Although the magnitude of this force is considered low, the chronic application of this force has been correlated with progressive degenerative injury to the IVD. As force is absorbed, the height of the IVD decreases, reducing the space between the vertebral bodies (Broberg, 1993; Haher et al., 1993; Nachemson, 1976; Reilly, 2010; Roaf, 1960; Sward et al., 1990; White & Panjabi, 1990). This spinal shrinkage occurs at a significantly greater amount within the lumbar region, compared to thoracic or cervical regions (Cavanaugh et al., 1980; Nachemson, 1976; Novacheck, 1997; White & Panjabi, 1990). Extensive research has demonstrated that differing running mechanics influence amounts of spinal shrinkage.

Ample research demonstrates the effectiveness of spinal unloading as a recovery technique from the effects of compressive forces, focusing on specific positions and populations (Healey et al., 2004; Fowler et al., 1994; Fowler et al., 2005; Gerke et al., 2011; Kanlayanaphotporn, Trott, Williams, & Fulton, 2001; Magnusson & Pope, 1996; Owens et al., 2009; Reilly et al., 1988; Rodacki et al., 2003; Rodacki et al., 2007). Limited research, however, has assessed the effectiveness of using spinal unloading to recover from the compressive force endured from running (Dowzer et al., 1998; Garbutt et al., 1989). The majority of these studies have assessed a single unloading position. Currently, only two studies have assessed effectiveness of multiple unloading positions (Gerke et al., 2011; Healey et al., 2004). No data exists for such a comparison after the completion of a running protocol.

The purpose of this study was unique as it assessed and compared multiple unloading positions within one study. By assessing the effectiveness of each position, a comparison could be made to determine if one yielded greater immediate benefits in recovery from spinal shrinkage. This will provide beneficial information for recreational runners of a potential injury prevention technique that is easily implemented in a variety of environments. Additionally rehabilitation specialists, coaches, and trainers can utilize this information to implement an effective recovery technique to reduce and prevent lumbar pain and injury of their clients.

Chapter 2

Review of Literature

Introduction

As a result of circadian variation and activities of daily living, an individual will experience a daily loss in overall stature up to 1% (Tyrell et al., 1985). This loss has been attributed to the intervertebral discs experiencing a reduction in height while absorbing compressive force as measured by relative changes in stature and cumulative disc height (Broberg, 1993; Haher et al., 1993; Nachemson, 1976; Roaf, 1960; White & Panjabi, 1990). Research indicates that increased acceleration and velocity of dynamic motion subsequently increases the rate and magnitude at which this shrinkage occurs (Broberg, 1993; Nachemson, 1976; Tyrell et al., 1985; Van Deursen et al., 2005; Wilby et al., 2005). Consequently, aggregate effects of static and dynamic compressive loading have been identified as probable mechanisms for spinal injury in running and other sport settings (Bohu et al., 2009; Broberg, 1993; Haher et al., 1993; Nachemson, 1976; Reilly, 2010; Roaf 1960; Sward et al., 1990; White & Panjabi, 1990). The practice of recovery techniques, such as spinal unloading, has demonstrated significant immediate benefits in reducing the effects of compressive force (Fowler et al., 1994; Fowler et al., 2005; Gerke et al., 2011; Healey et al., 2004; Rodacki et al., 2003; Rodacki et al., 2007). The following review of literature will provide the reader with a necessary framework of information to understand the purpose of this study. This chapter will introduce background information regarding the anatomy and mechanics of IVDs, an overview of various methods used to assess spinal shrinkage, the behavior of the IVDs during various physical activities, spinal shrinkage being a probable mechanism for injury, and the benefits of spinal unloading as a potential injury prevention technique.

Anatomy and Mechanics

The vertebral column is a complex structure composed of both osseous and soft tissue. Design of the vertebral column primarily provides structural support while facilitating motion, but also serves in protecting the spinal cord (Floyd, 2009; White & Panjabi, 1990). Vertebrae are arranged in an “s” pattern, which is subdivided into five regions: cervical, thoracic, lumbar, sacral, and coccygeal. The bony structures that make up these regions are characterized by distinct shape, increasing in size and thickness descending down the spine (Floyd, 2009; White & Panjabi, 1990). The lumbar region exhibits the largest and thickest vertebrae, serving as the region of the spine that absorbs the greatest amount of external force (Floyd, 2009; Nachemson, 1976; White & Panjabi, 1990).

Between each vertebra lies a soft-tissue structure called an intervertebral disc (IVD). While IVDs do aid in the mobility of the vertebrae, their principle purpose is to absorb and distribute external force between neighboring vertebral bodies. Each disc is composed of 3 parts: the nucleus pulposus, the annullous fibrosus, and the cartilaginous end plates (Bogduk and Twomey, 1997; Floyd, 2009; White & Panjabi, 1990). The nucleus pulposus composes the center of the IVD and consists of a gelatinous matrix of cartilage and water. Within young, healthy IVDs, water accounts for 70% to 90% of the structural components making up the nucleus pulposus. High volumes of water give the nucleus pulposus its fluid properties, while the configurations of proteoglycans and collagen fibrils contain the fluid and contribute to its viscosity and thickness. Surrounding the nucleus pulposus on either side are layers of collagen fibers arranged circularly, obliquely, and vertically, called the annullous fibrosus. Again, water serves as a primary structural component accounting for approximately 50% of the annullous fibrosus. Encasing these structures above and below are the cartilaginous end plates, which serve as attachment sites of the IVD to the adjacent vertebral bodies. These cartilaginous endplates are primarily composed of collagen fibers and very little water. Cooperative efforts of all anatomical structures contribute to the mechanical behavior of the vertebral column (Bogduk & Twomey, 1997; Floyd, 2009; White & Panjabi, 1990).

Water content, and thus cumulative disc height, are constantly fluctuating due to circadian variation and activities of daily living. External forces resulting from motion, muscle activation, and gravity apply compressive loads to the vertebral column (Broberg, 1993; Haher et al., 1993; Nachemson, 1976; Roaf, 1960; White & Panjabi, 1990). As this load is absorbed, intradiscal pressure increases and gelatinous fluid is expelled from the nucleus pulposus. This fluid is then absorbed in the vertebral bodies by way of the cartilaginous end plates (Broberg, 1993; Haher et al., 1993; Nachemson, 1976; Roaf, 1960; White & Panjabi, 1990). As the fluid is lost from the discs, the annular fibers begin to bulge resulting in deformation of disc shape and reduction of the space between the vertebral bodies. This spinal shrinkage continues until the compressive force ceases or is removed (Broberg, 1993; Haher et al., 1993; Nachemson, 1976; Roaf, 1960; White & Panjabi, 1990).

Assessment of Spinal Shrinkage

Assessing spinal shrinkage has become a common method for measuring the effects of compressive force upon the spine. Spinal shrinkage is indicated as a change in overall stature and IVD height (Carigg & Hillemeyer, 1992; Dmitriadis et al., 2011; Dowzer et al., 1998; Fowler et al., 2005; Garbutt et al., 1990;

Kingsley et al., 2012; Leatt et al., 1986; Reilly, 2010; Roush et al., 2004; Seay et al., 2008; White & Malone, 1990). Computer-aided stadiometry, as originally described by Boocock et al. (1986), is used as the standard method for assessing changes in overall stature (see Figure 1). Participants rest against an aluminum frame reclined at 15°. Rods and plates are adjusted to provide postural control and alignment of the head. Vertical displacement is measured by two strain gauges and displayed on an attached microcomputer. Design of the stadiometer having adjustable rods and plates allows for reproducibility of each individual's spinal contours, controlling for inter- and intra-individual variability. The attached strain gauges and microcomputer reduce the chance of researcher error and variability with reading measurements. A highly specialized design allows for a measurement precision of 0.01 mm (SD less than 0.005) (Boocock et al., 1986). It is assumed that any loss of stature recorded reflects a reduction in height of the IVDs. However, soft tissue deformation within the lower extremities may also contribute to loss of stature. This machine only provides measurements in overall stature with no distinction between changes in spine versus the lower extremities. Access to this apparatus is also limited and costly.

Figure 1. Computer-aided stadiometer described and used by Boocock et al. (1986).

Advances in technology, such as radiographic imaging, reveal more detailed *in vivo* assessments of the effects of compressive force upon the spine. Computerized tomography (CT) and magnetic resonance imaging (MRI) are the preferred methods as they provide a direct image of the intervertebral discs (Carigg & Hillemeyer, 1992; Dmitriadis et al., 2011; Kadziolka et al., 1981; Kingsley et al., 2012; Ledsome et al., 1996; Naish et al., 2003; Shao, Rompe, & Schiltenwolf, 2002). These images have aided in the understanding of structure and function within the intervertebral discs. Often CT and MRI are accompanied by injection of a contrast dye to produce images that can isolate the various parts of the IVD and identify degenerative pathologies. Images have also been used to measure IVD height and behavior of the discs in response to application of compressive force (Chin, 2012; Karmakar et al., 2009; Loizides et al., 2011). Although the use of an MRI and CT scan produces the most precise measurement of spinal shrinkage, conducting these assessments is both costly and relatively invasive.

More recently, researchers have validated diagnostic ultrasound (DUS) as a less expensive and less invasive radiographic imaging technique to assess spinal shrinkage (Chin, 2012; Karmakar et al., 2009; Loizides et al., 2011). While the device does not provide a direct image of the IVD, changes in disc height can still be assessed through paramedian sagittal views of the vertebral bodies and IVD space (Chin, 2012; Karmakar et al., 2009; Loizides et al., 2011). This imaging process is similar to that used when guiding injections into the spine for epidurals, nerve blocks, and anesthesia. By placing the transducer 5 cm lateral to the midline of the spine in a longitudinal position, a two-dimensional, real-time image of the transverse processes is displayed. It is assumed that the space between the processes represents the IVD, and distances measured reflect aggregate disc height. Any reductions in the distance between the transverse processes are considered an index of spinal shrinkage. Several studies have determined IVD height through measuring the distances between the transverse processes of the vertebral bodies within the cervical, thoracic, and lumbar regions (Carigg & Hillemeyer, 1992; Dmitriadis et al., 2011; Kadziolka, 1981; Kingsley et al., 2012; Ledsome et al., 1996; Naish et al., 2003; Shao et al., 2002). When compared to the precision of using an MRI or CT, the DUS was within .09% (SD ± 4%) (Carigg & Hillemeyer, 1992; Dmitriadis et al., 2011; Kadziolka, 1981; Kingsley et al., 2012; Ledsome et al., 1996; Naish et al., 2003; Shao et al., 2002).

Spinal Shrinkage and Physical Activity

During physical activities, intervertebral discs experience external loading and decrease in height as they are compressed. Spinal shrinkage occurs when the external compressive load exceeds the intradiscal pressure within a fully hydrated disc. Initial research theorized that aggregate spinal shrinkage correlated with the rate and magnitude that compressive force is applied. Nachemson et al. (1976) performed *in vivo* measurements of intradiscal pressure within the lumbar spine while participants performed various seated, standing, and supine static positions. A specially designed needle was inserted into the nucleus pulposus of the lumbar vertebrae of the participants while they performed the different static positions, and an externally attached pressure transducer recorded intradiscal pressure measurements. Results indicated that sitting positions produced significantly greater intradiscal pressure than standing or supine positions. In comparison to seated positions, an average decrease of intradiscal pressure by 30% was exhibited in standing positions and by 50% in supine positions (Nachemson et al., 1976). Research by Wilke et al. (1999) further supported the findings of Nachemson and colleagues by recording measurements of intradiscal pressure within the lumbar vertebrae while participants performed various static positions and activities of daily living. Measurements were recorded using a similar *in vivo* methodology as described by Nachemson et al. (1976). Results for static positions were consistent with Nachemson et al. (1976), revealing significantly greater intradiscal pressure in seated positions versus standing or supine. Results by Wilke et al. (1999) also revealed a correlation between an increase in velocity and acceleration of dynamic motion and intradiscal pressure. For example, jogging with tennis shoes created greater intradiscal pressure (0.53-0.95 MPa) than walking with tennis shoes (0.35-0.65 MPa).

Physical activities are characterized by rapid and/or repetitive motions that expose the body to compressive loads that exceed those typically experienced during activities of daily living. The consequence is an increase in aggregate spinal shrinkage. Changes in total body length and IVD height have been used to examine the effects of physical activity that apply compressive load to the spine. It is assumed increased velocity and acceleration of dynamic motion imposes a greater compressive load on the spine, and thus greater spinal shrinkage is incurred. Consequently, it is assumed the risk of lumbar pain and injury increases. Observations of various physical activities reveal a relationship between the magnitude and rate that compressive force is applied and the shrinkage induced in the spine. Depending upon the physical activity, compressive force is applied either acutely or chronically and at high or low magnitudes. Research indicates that these varying rates and magnitudes may influence the resultant spinal shrinkage.

Acute compressive force. Acute applications of compressive force involve a rapid increase of intradiscal pressure and sudden IVD shrinkage. Athletes who participate in high-impact sports such as gymnastics, football, and weightlifting are exposed to these high magnitudes, acute compressive forces. Tyrell et al. (1985) assessed the rate of spinal shrinkage when static shoulder loads were applied using rucksacks and barbells. During 20 minute sessions, observations were completed during 2 minute intervals. Overall results indicated a linear relationship between increased external load and spinal shrinkage. The average amounts of spinal shrinkage steadily increased as barbell weight was increased: 5.14 mm (10 kg), to 7.11 mm (20 kg), 9.42 mm (30 kg) and 11.2 mm (40 kg) (Tyrell et al., 1985). Similar results were observed in a study conducted by Leatt et al. (1986) that analyzed the rate of spinal shrinkage among nine male participants as they completed a circuit of nine different weight lifting exercises. Weights varied from 14 kg to 32 kg throughout the various exercises. After completing the circuit for 25 minutes, measurements were recorded revealing a mean shrinkage of 5.49 mm (Leatt et al., 1986). This same workout regimen was replicated and assessed with a group of female subjects by Wilby et al. (1987). Female subjects completed the workout once in the morning and once in the evening. Results from each were compared to assess the effect of diurnal variation on spinal shrinkage following physical activity. A greater rate of spinal shrinkage was observed in the morning (5.4 mm) than in the evening (4.3 mm). An additional comparison was made with results from Leatt et al. (1986) revealing no significant difference between genders in the amount of weightlifting-induced spinal shrinkage.

Jumping and bounding are rapidly occurring dynamic motions that are found in many sports and training regimens. The impact from landing and take-off induces an acute, short duration, high magnitude force applied to the body. Considerable work by Boocock et al. (1988; 1989) sought to determine the effect these activities have on the rate of IVD shrinkage. During one experimental procedure, participants were required to complete 10 sets of 5 standing broad jumps, with a 15 second interval rest between each jump. Results revealed a mean shrinkage of 1.7 mm (Boocock et al., 1988). Another study by Boocock et al. (1989) involved subjects completing a series of 5 drop jumps from a height of 1 meter, immediately followed by a rebound over a hurdle 0.5 meters high. Results from this study indicated a mean spinal shrinkage of 1.74 mm (Boocock et al., 1989).

Chronic compressive force. Ground reaction force (GRF) is the most common form of compressive force experienced by the body. Ground reaction force is generated from any form of human locomotion, at the point when the foot strikes the ground. When running, GRF is equivalent to 2-4 times body weight (approximately 2000 N). This GRF is transmitted to the spine each time the foot strikes the ground (approximately 600-1200 times per 1 km). Values for compressive force exceed those that are typically experienced with static loads or activities of daily living, suggesting that rates of observed shrinkage will be greater as a result of the increased load on the spine. Research indicates that various mechanical and physiological factors of the runner may influence the amount of GRF experienced and subsequent shrinkage incurred.

Mechanical factors. Initial research by Leatt et al. (1986) compared experienced and novice runners during a 30 min run on a treadmill at 12.2 km/hr. Researchers observed that running experience had no significant effect on the amount of shrinkage induced. Stature recordings following the run indicated aggregate shrinkage being 2.35 mm for the experienced running group and 3.26 mm for the novice running group (Leatt et al., 1986). Further stature loss was recorded (7.79 mm) among experienced runners who completed an additional 19 km run; suggesting duration had a greater influence than distance or experience in the amount of shrinkage experienced by runners (Leatt et al., 1986).

Reilly et al. (1988) compared the effects of running continuously versus running intervals. Two groups of runners covered a distance of 10 km in 40 min, one running continuously and the other alternating a fast and slow pace. Although pace varied between the two groups, results indicated no significant difference in the amount of shrinkage incurred once distance and duration of the run were equal. Consistently both groups exhibited that the greatest amount of shrinkage within the first 15 minutes of the run (Reilly et al., 1988). Findings by Roush et al. (2004) support the idea that the greatest amount of shrinkage occurred in the early part of the run (within the first 15 minutes). Twenty male participants completed a 3 mile run at a self-selected pace. Stature measurements were recorded at half-mile intervals, revealing the greatest amount of shrinkage was produced within the first mile of the run. Shrinkage continued to increase until mile 2.5 and no change in stature was recorded between 2.5 and 3 mile distances (Roush et al., 2004). Overall, it appears that duration may be an integral factor to the amount of shrinkage incurred.

Research by Garbutt et al. (1989) assessed the influence of running intensity on rate of induced shrinkage. A group of 5 male runners were required to run on a treadmill for 30 minutes at 75%, 85%, and 100% of their self-selected marathon pace. Stature measurements were completed after the first 15 min of the run and at the conclusion of an additional 15 min run. Mean values reported for stature losses were: 4.25 mm, 3.37 mm, and 3.97 mm. Following the final 15 min run, mean stature losses reported were: 0.91 mm, 1.06 mm, and 2.63 mm. Results indicate that as intensity increases, so does the rate of induced shrinkage (Garbutt et al., 1989). Additionally, findings support those from prior studies that the greatest amount of shrinkage was induced in the first 15 min of the run regardless of intensity. Kingsley et al. (2012) found similar results that spinal shrinkage increased as intensity increased, when participants completed a 30 min run on a treadmill at varying intensities. Although changes were nonsignificant, results from digitized MRI scans revealed a mean reduction in IVD height of 6.3% ±0.9% following moderate intensity running and 6.9% ±1.0% following high-intensity running (Kingsley et al., 2012).

A study conducted by Seay et al. (2008) found stride length and pace to be additional factors that influence spinal shrinkage. Participants were required to run a distance of 3.8 miles at three stride lengths: preferred stride length, 20% greater than preferred, and 20% less than preferred length. A Newton-Euler inverse dynamics model that included reaction force and moment estimation at the L5-S1 and T12-L1 vertebrae indicated an increase in peak GRF and shrinkage incurred as stride length was increased (Seay et al., 2008).

Physiological factors. Physiological factors including age, height, weight, sex, and musculoskeletal health of the spine influence rates of running induced spinal shrinkage. Using an MRI scanner, the lumbar spines of 25 long-distance runners were assessed by Dmitriadis et al. (2011). Comparisons were made between rates of IVD height reduction and age, weight, height, and sex (male *n* = 15, female *n* = 10; age 23-69 years). Further analysis subdivided the runners according to the pre-existence of lumbar pain or injury. Runners were measured in three positions (neutral sitting, leaning forward, and leaning backwards), pre and post a 1 hr run at a self-selected pace. Results indicated significantly greater rates of shrinkage among participants who reported a higher weight or height. No significant differences were reported between age groups or sex. Regardless of height and weight, individuals who reported pre-existing lumbar pain or injury demonstrated the greatest reduction in disc height (Dmitriadis et al., 2011).

Results from Ahrens et al (1994) similarly reported no significant difference in rates of induced shrinkage between age and sex following a 6 mile run at a self-selected pace (male *n* = 17, female *n* = 14; age = 20-57 years).

Garbutt et al. (1990) conducted a subsequent study assessing the influence of running intensity on shrinkage among runners with and without lumbar pain. Two groups of 7 male runners completed a 30 min run on a treadmill at 70%, 85%, and 100% of their self-selected marathon pace. Using a stadiometer, stature measurements were recorded. Results indicated that shrinkage was greater during the first 15 minutes of the run 3.26 mm (±2.78 mm) compared to 2.12 mm (±1.61 mm) during the second 15 min of the run. Consistent with previous research (Garbutt et al., 1988) rates of shrinkage increased as running intensity increased: 3.37 mm (±2.38 mm) at 70%, 5.10 mm (±1.90 mm) at 85%, and 7.69 mm (±3.69 mm) at 100%. Contrary to Dmitriadis, results indicated no significant difference in rates of shrinkage between groups with and without low back pain (Garbutt et al., 1990). Researchers attribute these findings to the notion that low back pain is independent from the shrinkage observed due to running.

Mechanism for Injury

The incidence of injury to the IVD is not solely related to the application of compressive force or occurrence of spinal shrinkage. Research indicates injury of IVD is mainly dependent upon the rate and magnitude which compressive force is applied (Broberg, 1993; Nachemson, 1976; Sward et al., 1990; White & Panjabi, 1990). External loads from supporting the body's weight to maintain an erect posture and performing ADLs subject the IVDs to a constant, low magnitude compressive force that is more easily absorbed (Nachemson et al., 1976; Wilby et al., 1999). However, vigorous athletic activities involve rapid, repetitive motions that vary the magnitude and rate that compressive force is applied, increasing the likelihood of sustaining pain or injury to the lumbar spine (Broberg, 1993; Nachemson, 1976; Sward et al., 1990; White & Panjabi, 1990).

The lumbar spine is at greater risk of injury to its IVD than other regions of the spine due to its mechanical structure. The lumbar region links the upper body with the pelvis, and as such, must support the weight of the upper body while absorbing the majority of applied forces. When performing ADL, the intervertebral discs carry 75% to 95% of the compressive load applied to the spine. Additionally, the anatomical position of the sacrum is naturally tilted anteriorly between 30-40°, which increases potential for the occurrence of injury. When compressive force is applied, the lumbosacral angle causes the force to travel in two different directions: perpendicularly causing vertical compression upon the disc and anteriorly causing shearing force. This diversion in the path that the force travels places excessive strain upon the annular fibers of the IVD.

The most common form of injury that arises within the IVD is due to the degeneration or weakening of the annular fibers in response to absorbed loads. These injuries are characterized as being chronic or catastrophic, and are subdivided into bulging and herniated discs respectively. As previously discussed, a mild swelling of the disc and protrusion of the nucleus pulposus in response to the absorbed load occurs naturally. Provided the nucleus is thoroughly hydrated and annular fibers are well nourished, typically no pain is experienced. The absorption of compressive force in any amount results in a loss of nuclear fluid. Even slight dehydration decreases the ability of the discs to withstand repetitive application of compressive force. Before successive loads are applied, discs are unable to recover and allow fluid to accumulate within the nucleus pulposus. Similar to a stretched rubber band, the structural integrity of the IVD is stressed as external compressive loads are applied, ultimately resulting in a loss of turgor and viscoelasticity within the annular fibers. Degeneration begins with the most central fibers as they are the least resistant to compressive force, spreading distally to the outermost fibers of the annullous fibrosus. The nucleus pulposus begins to protrude distally through the degenerated fibers, creating a bulge. Once the fibers are completely torn, the nucleus pulposus extrudes, creating a herniation.

The prevalence of catastrophic IVD injury has been extensively researched and observed within high-impact sports such as gymnastics, weightlifting, and football (Bohu et al., 2009; Haher et al., 1993; Nachemson, 1976; Reilly, 2010; White & Panjabi, 1990). These sports expose the vertebral column to acute application of excessive compressive force resulting in a high occurrence of herniated disc injuries (Nachemson, 1976; White & Panjabi, 1990). Endurance sports, such as running, expose the body to a chronic application of lower magnitude compressive force equivalent to approximately 2 to 4 times body weight each time the foot strikes the ground (Cavanaugh, 1990; Nachemson, 1976; Novacheck, 1997). Variation in running mechanics and techniques including speed, intensity, and stride length influence the amount of GRF absorbed studies have indicated running having a degenerative effect upon IVDs (Dowzer et al., 1998; Garbutt et al., 1989; Kingsley et al., 2012; Roush et al., 2004). Sward et al. (1990) assessed degenerative effects of GRF upon the spine, reporting levels of degeneration at 75% among experienced runners compared to 31% among non-runners, also identifying a non-herniated disc being as a probable mechanism for lumbar pain and injury. Continued exposure to chronic compressive loading on the spine results in an accelerated rate of degeneration of the IVD (Garbutt et al., 1989; Sward et al., 1990; White & Panjabi, 1990).. Ultimately, the likelihood of sustaining further catastrophic injury and pain increases due to the reduced functionality of the IVDs. As a result, additional anatomical structures such as the spinal column, nerves, ligaments, muscles, and bony structures become exposed to the effects of compressive force.

Limited research has focused upon methods, such as spinal unloading techniques, to recover from the effects of compressive force and its potential for injury prevention.

Spinal Unloading

Spinal unloading techniques involve reducing the effects of gravity by manipulating the position of the body, thus promoting elongation of the spine (Garbutt et al., 1990). Isolated assessments demonstrate various standing, seated, inverted, and supine positions effectively reduce spinal shrinkage, with inverted and supine positions yielding the greatest immediate benefits (Fowler et al., 1994; Fowler et al., 2005; Gerke et al., 2011; Healey et al., 2004; Rodacki et al., 2003; Rodacki et al., 2007).

According to Nachemson et al. (1976) and Wilke et al. (1999), seated static positions resulted in the highest intradiscal pressure. However, altering the sitting pattern changed the amount of pressure exhibited. For example, sitting actively with a straightened back produced a pressure of 0.55 mega pascals (MPa), whereas sitting relaxed against a backrest produced a lower pressure of 0.45 MPa (Wilke et al., 1999). Healey et al. (2004) assessed the effectiveness of four different positions, including one seated position with participants resting while supported by a backrest reclined at 110°. Two groups of participants, with and without back pain, walked at a self-selected pace on a treadmill for 10 min while wearing a weighted vest (10% of body weight) to induce spinal shrinkage. Stature measurements were recorded pre and post the walking intervention and again pre and post the assigned unloading position. Results from measurements taken for the seated position condition revealed a significant stature recovery (% stature loss) for both the group with low back pain (42.8% ± 23.5%) and the group without low back pain (73.1% ± 29.1%). Although these results reveal some immediate benefit in recovering from spinal shrinkage, they were significantly lower than the other positions assessed (side lying, gravity inversion, and supine with hyperextension) (Healey et al., 2004). Owens et al. (2009) also assessed the effectiveness of a seated position in recovering from spinal shrinkage. Following a period of weighted sitting for 10 min, changes in sitting height measurements were recorded. Participants then performed a recovery phase for 10 minutes in either a seated position with hyperextension or supine position with flexion. Another series of sitting height measurements were recorded. Results revealed a significant increase in sitting height following both supine flexion and seated with hyperextension. Although there was a no significant difference in stature recovery between the two positions, the supine with flexion position exhibited a greater recovery (3.19 mm) than the seated with hyperextension (3.11 mm) (Owens et al., 2009). Overall, these findings suggest the potential of a relaxed seated position accompanied by a reclined backrest may provide immediate benefit in reducing intradiscal pressure and recovery from spinal shrinkage. Nonetheless, when compared to the effectiveness of other spinal unloading techniques, these gains in stature are small. Additionally, the seated position still exposes the spine to a compressive force through the presence of gravity and support of body weight.

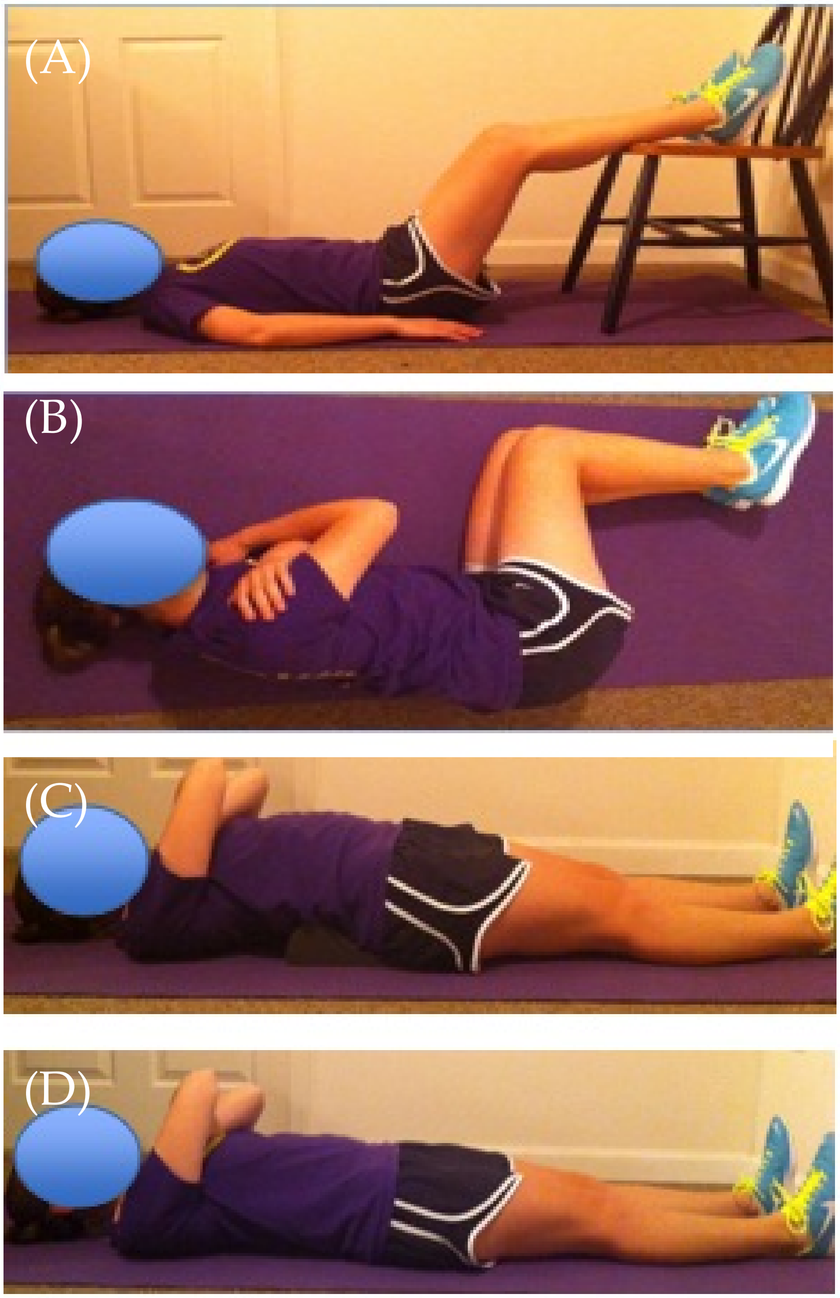
In comparison to a seated position, an average decrease in intradiscal pressure by 30% is exhibited in standing positions (Nachemson et al., 1976). Wilke et al. (1999) reported that a relaxed standing position produced pressures of approximately 0.5 MPa. However, standing with spinal flexion significantly increased the pressure produced up to 1.10 MPa (Wilke et al., 1999). A relaxed standing position, with weight evenly distributed, has demonstrated effectiveness in recovering from spinal shrinkage. In a study by Leatt et al. (1986) participants performed four different exercise conditions followed by a 20 min period of recovery. Recovery occurred with the participants standing relaxed with weight evenly distributed. Results revealed significant losses in stature following each exercise regimen; however, no significant recovery was observed during the 20 min recovery period (Leatt et al., 1986). Fowler et al. (1994) assessed stature changes following 50 unloaded box jumps, 50 loaded box jumps, and loaded standing conditions. Mean stature losses for each condition were 0.62 mm (± 0.43 mm), 2.14 mm (± 1.56 mm), and 0.33 mm (± 0.27 mm). Following each condition, a recovery period of 20 min was performed with participants in a standing position with weight evenly distributed. Stature measurements were found to increase by 0.55 mm (± 0.3 mm), 0.73 mm (± 0.42 mm), and 0.16 mm (± 0.14 mm) during the recovery period following the unloaded drop jumps, loaded drop jumps, and standing conditions, respectively. Similar to Leatt et al. (1986), results also revealed increases in stature observed during the recovery phase to be not significant. These findings suggest that standing is an ineffective spinal unloading technique. Similar to seated positions, standing positions continue to expose the spine to a compressive force by supporting the weight of the body and presence of gravity. Spinal unloading positions that reduce or eliminate the compressive effects of gravity and body weight would be more effective.

Gravity inversion involves the body being positioned upside down or at an inverted angle. In this position, gravity acts as a tensile force, allowing the spine to decompress and elongate. Multiple studies have assessed the benefits of gravity inversion in recovering from spinal shrinkage. In a study by Boocock et al. (1988) participants performed ten sets of 5 standing broad jumps, with a 15 s recovery between each set. Mean stature losses measured 2.7 mm. Ten minute periods of gravity inversion with the subjected inverted at 50° were performed before and after the exercises. Significant gains in stature were recorded during the gravity inversion that was performed following the broad jump exercises (3.5 mm) (Boocock et al., 1988). Another study investigated the impact of gravity inversion following a drop-jump exercise regimen (Boocock et al., 1989). Participants performed five sets of five drop-jumps from a height of 1 m. Upon impact, participants immediately rebounded over a hurdle 0.5 m high. This resulted in a mean stature loss of 1.74 mm. Immediately following the drop-jump session, a 20 min period of gravity inversion was performed. Results indicated a significant gain in stature of 5.18 mm following the gravity inversion period (Boocock et al., 1989). Findings suggest gravity inversion yields the greatest immediate benefits in recovering from spinal shrinkage compared to standing and seated unloading positions. To safely and effectively perform gravity inversion requires specialized equipment and training. Access to this equipment and personnel can be limited and costly. The frequent use of gravity inversion may also have negative health implications including: damage to the eyes, damage to the middle ear, and abnormal circulation of blood. Supine unloading positions, however, allow for a similar ability to reduce the effects of gravity and allow elongation of the spine without increased health implications or cost.

Supine positioning reduces intradiscal pressure by as much as 50%, in comparison to seated or standing positions (Nachemson et al., 1976). Similarly, *in-vivo* measurements by Wilke et al. (1999) found that supine positions produced the lowest values of intradiscal pressure (0.10 MPa-0.25 MPa). Variations in these values for intradiscal pressure are attributed to alterations in position patterns. For example, the pressure produced in a relaxed supine position at 0.10 MPa is less than lying on the side at 0.12 MPa (Wilke et al., 1999). Researchers have extensively investigated the effectiveness of numerous variations of supine positions, the most common being: the Fowler position, side lying with spinal flexion, supine with hyperextension or lumbar support, and relaxed supine.

Fowler position. The Fowler position is the most commonly assessed supine unloading technique (Dowzer et al., 1997; Owens et al., 2009; Rodacki et al., 2007; Wilby et al., 2007). Although there are several variations, researchers consistently describe participants lying in a relaxed supine position with legs elevated on a rigid surface. Flexion angles of the hips and knees are approximately 45°. Feet are shoulder width apart and ankles dorsiflexed. Arms are either extended to the side of the body, resting upon the floor or folded across the chest with hands resting on opposing shoulders (Figure 2 (A) (Dowzer et al., 1998; Rodacki et al., 2007; Wilby et al., 2007).

Figure 2. Supine spinal unloading positions to be assessed: (A) the Fowler position, (B) side lying with spinal flexion, (C) supine with lumbar support, and (D) relaxed supine.


(A)
(B)
(C)
(D)

Wilby et al. (1987) assessed the circadian variation of stature in females and the effects of compressive loading with specific times of the day. Participants performed two sessions of 20 min circuit training with weights. These exercises were immediately followed by a 20 min period of spinal unloading in the Fowler position. These sessions were performed once in the morning and once in the evening. Results revealed significantly greater height losses during the morning sessions (5.4 mm) than in the evening (3.4 mm; $p < 0.001$). However, significant gains in stature were also observed when particpants performed the Fowler position for both conditions at 4.5 mm and 3.4 mm respectively ($p < 0.05$) (Wilby et al., 1987). Similar results were found by Dowzer et al. (1997) who employed a recovery period using the Fowler position when comparing rates of stature loss in three running conditions: running in shallow water, running in deep water, and running on land. For each condition, participants ran two 15 min interval runs. Following the second 15 min interval run, subjects performed a 20 min recovery period in the Fowler position. Results indicated a significant gain in stature in all conditions ($p < 0.05$). In another study the Fowler position was compared to a sitting position with the back hyperextended (Owens et al., 2009). Participants performed a 20 min recovery period in either the hyperextended sitting position or Fowler position following a session of loaded sitting. Results indicated a significant increase in stature following both unloading positions ($p < 0.0001$). Although there was no significant difference between the two positions ($p = 0.927$), the Fowler position resulted in greater increases in height (3.19 mm) than the sitting position (3.11 mm) (Owens et al., 2009). Rodacki et al. (2007) sought to compare the acute effectiveness of two abdominal exercises with the Fowler position in recovering from the effects of spinal shrinkage. Subjects performed a loading protocol consisting of three sets of military press followed by three unloading protocols: 3 sets of regular abdominal exercises, 3 sets of abdominal exercises on an incline board, and the Fowler position. Significant increases in stature (% stature recovery) were seen among all conditions ($p < 0.05$), however, greater increases were observed in the abdominal exercise conditions (regular 87.8% ± 20.4%; incline 70.1% ± 14.5%) in comparison to the Fowler position (33.6% ± 14.1%). The use of the Fowler position consistently demonstrates significant gains in stature following a period of spinal loading.

Side lying with spinal flexion. Side lying with spinal flexion is another position that has commonly been assessed (Fowler et al., 2005; Healey et al., 2004; Rodacki et al., 2003). In this position the subject lies on their left or right side with the hips and knees flexed at approximately 90° and ankles dorsiflexed. Arms are folded across the chest with hands resting on opposing shoulders (Figure 2 (B). Rodacki et al. (2003) assessed the effectiveness of the side lying position with spinal flexion in stature recovery between three groups of women: control, pregnant with low back pain, and pregnant without low back pain. Stature measurements were recorded before and after participants performed a dynamic physical activity, and once again following a recovery period in the side lying unloading position. Although results indicated no significant difference in the amount of stature loss following the physical activity ($p > 0.05$), the use of side lying with spinal flexion as an unloading technique resulted in a significant increase in stature recovery in all groups ($p < 0.05$). The control group exhibited a greater amount of stature recovery (111.2% ± 13.6%) than the pregnant women with and without low back pain (76.2% ± 23.38%) (Rodacki et al., 2003). A subsequent study utilized the same experimental protocol as Rodacki et al. (2003) with two groups of women with and without low back pain (Fowler et al., 2005). Similarly, results indicated no significant difference in the amount spinal shrinkage that occurred between each group ($p > 0.05$), and that the use of the side lying spinal unloading position resulted in significant increase in stature recovery in both groups ($p < 0.05$). Once again, the control group of women without low back pain exhibited the greatest amount of stature recovery (111.2% ± 13.6%) than the group with low back pain (57.5% ± 25.1%) (Fowler et al., 2005).

Additional research has compared the effectiveness of side lying with spinal flexion to other unloading positions including gravity inversion, supported sitting, and supine with hyperextension (Healey et al., 2004). Stature recovery and paraspinal muscle activity were assessed with two groups of subjects with and without low back pain. After completing a loaded walking task (10 kg weighted vest) at a self-selected pace, subjects completed each of the four unloading positions over the course of four separate testing sessions. No significant difference was found with regard to the reduction in stature resulting from the loaded walking task between groups or testing sessions ($p < 0.05$). Both groups experienced significant recovery in stature, with side lying yielding the second greatest amount of stature recovery (with LBP 47.7% ± 26.9%; without

LBP 74.6% ± 22.1%), in comparison to gravity inversion (with LBP 74.4% ± 30.3%; without LBP 116.9% ± 31%), supported sitting (with LBP 43.6%; without LBP 73.3% ± 29.1%), and supine with hyperextension (with LBP 42.8% ± 23.5%; without LBP 73.1% ± 27.8%) (Healey et al., 2004). Findings suggest that side lying with spinal flexion may yield significant acute benefits to individuals without low back pain in recovering from the compressive effects of spinal shrinkage (up to 100%).

Supine with Lumbar Support. Researchers have examined the effectiveness of having subjects lie in a supine position with the spine hyperextended (Healey et al., 2004; Magnussen and Pope, 1996). Subjects lie in a supine position with legs fully extended. Feet are shoulder width apart and ankles dorsiflexed. Foam fulcrum and support devices are placed under the lumbar region of the spine to cause hyperextension of the spine. Arms are extended to the side of the body, resting upon the floor or folded across the chest with hands resting on opposite shoulders (Figure 2 (C) (Healey et al., 2003; Magnussen & Pope, 1996; Owens et al., 2009). Magnussen and Pope (1997) sought to determine if overall body height could be increased by hyperextension of the spine. Subjects performed a period of loaded sitting with 10 kg weights. Recovery periods with subjects in a seated position and the supine position with hyperextension of the spine followed. Results indicated that the supine position with hyperextension of the spine caused greater increases in body height in comparison to the relaxed seated position (Magnussen & Pope, 1997). Comparisons between supine positioning with hyperextension, gravity inversion, side lying with spinal flexion, and supported sitting were observed by Healey et al. (2004). As previously discussed, this study assessed the effectiveness of four spinal unloading techniques between two groups of subjects, with and without low back pain. All positions demonstrated a significant amount of stature recovery in both groups ($p < 0.05$). However, in comparison to the other spinal unloading techniques, the supine position with hyperextension of the spine resulted in the lowest amount of stature recovery in both groups (With LBP 42.8% ± 23.5%; Without LBP 73.3% ± 27.8%) (Healey et al., 2004). Findings indicate that lying in a supine position with the lumbar spine hyperextended allows the spine to recover. Although the amounts of recovery are lower in comparison to other techniques, this recovery is still a significant amount (Healey et al., 2004; Magnussen and Pope, 1997).

Overall results indicate that manipulating the body in a supine position yields significant immediate benefits in recovering from spinal shrinkage. Based upon current research, it seems side lying with spinal flexion elicits greater amounts of recovery than the Fowler position or supine with hyperextension. However, currently only two studies have compared the effectiveness of multiple supine positions (Gerke et al., 2011; Healey et al., 2004). Limited analysis of these positions has followed the conclusion of dynamic physical activity (Healey et al., 2004). Some research assessing effects of GRF on stature and IVD height while running employs a spinal unloading technique before experimental protocol to control for stature loss due to circadian variation and activities of daily living (Ahrens, 1994; Carigg & Hillemeyer., 1992; Dowzer et al., 1998; Garbutt et al., 1990; Kinglsey et al., 2012; Leatt et al., 1986; Seay et al., 2008). Only two studies have employed an unloading position before and after experimental protocol (Dowzer et al., 1998; Garbutt et al., 1990). Each of these studies assessed only one position. Currently, no study has assessed the effectiveness of multiple unloading positions in immediately recovering from the compressive effects of GRF on stature and IVD height induced while running. Employing supine spinal unloading techniques may reduce the impact of compressive loading and its associated effects. Recovery time for the IVDs may increase and diminish the potential for lumbar pain or injury.

Chapter 3

Methods

Introduction

The purpose of this study was to assess the immediate effectiveness of multiple spinal unloading positions in recovering from spinal shrinkage incurred while running in recreational runners. A within-subjects experimental design was used with one group of participants performing four levels of the independent variable, spinal unloading position (Fowler, side lying with spinal flexion, supine with lumbar support, and supine with no support). The dependent variable, spinal shrinkage, was assessed upon the conclusion of the experimental protocol of running and unloading positions. This chapter presents the methodology used for this study including: participant selection, instrumentation, procedures, and statistical analysis for this study.

Selection of Participants

Participants for this study were composed of a convenience sample including undergraduate and graduate students from Eastern Washington University (EWU) in Cheney, Washington. Solicitation for participation occurred through visual recruitment posters and verbal invitation by the researcher within the University Recreation Center, group exercise classes, and Physical Education, Health, and Recreation department academic classes.

Informed consent was received from the participants per guidelines set by EWU Institutional Review Board for use of human participants. A questionnaire accompanied this consent form and included questions addressing demographics, injury history, and running history to determine if participants met eligibility criteria. Inclusion criteria encompassed healthy male and female adults aged 18 to 35 years who engage in recreational running. Physical activity guidelines set by the Centers for Disease Control and Prevention (CDC, 2012) were used to define running as working at a vigorous intensity level of 5 km/hr or greater for a duration of at least 20 min. Recreational running was defined according to Running USA (2011) as engaging in running between 50-110 days per year, averaging 1-3 times weekly. Prior studies assessing spinal shrinkage commonly recruited individuals aged 17 to 35 years (Ahrens, 1994; Carigg & Hillemeyer, 1992; Dmitriadis et al., 2011; Dowzer et al., 1998; Garbutt et al., 1989; Garbutt et al., 1990; Kinglsey et al., 2012; Leatt et al., 1986; Reilly et al., 1988). Individuals aged 35 years and older are typically excluded due to the observed musculoskeletal changes in the spine as a result of aging. As age increases fluid content within the IVD decreases, thereby increasing rigidity of the disc and altering its viscoelastic capabilities (Kapandji, 1974; Kraemer et al, 1985). Studies have demonstrated no significant difference in the amount of spinal shrinkage between sexes; thus both males and females were recruited for participation within this study (Leatt et al., 1986; Wilby et al., 1987).

Runners reporting a history of musculoskeletal injury to the spine within one year prior to the study and/or currently experiencing pain within the spine or back were excluded from participation (Dowzer et al., 1997; Fowler et al., 2005; Healey et al., 2004; Kanlayanaphotporn et al., 2001). Research has indicated traumatic or chronic injury to the spine can compromise the structural integrity of the IVD, thereby potentially negatively impacting the ability of the spine to adequately absorb and recover from compressive loading (Broberg, 1993; Nachemson et al., 1976; Sward et al., 1990; White & Panjabi, 1990). Studies determining if low-back pain (LBP) impacts the rate of spinal shrinkage have demonstrated inconsistent results (Boocock et al., 1989; Dmitriadis et al., 2011; Fowler et al., 2005; Garbutt et al., 1990; Rodacki et al., 2003). Several studies have indicated that although rates of spinal shrinkage may be consistent among individuals with and without LBP, those individuals with LBP demonstrate significantly reduced rates of recovery compared to those without LBP (Fowler et al., 2005; Garbutt et al., 1990; Rodacki et al., 2003). Individuals reporting additional musculoskeletal, neurological, or disease limitations that would impede their ability to perform a 15 min run or maintain a supine position for the duration of 20 min were excluded.

Effect sizes for this study were calculated using the University of Colorado, Colorado Springs Effect Size Calculator (http://www.uccs.edu/~lbecker/). Effect sizes were derived from four separate studies assessing the different spinal unloading positions being utilized in this study. Dowzer et al (1997) indicated an effect size of $d = 0.3$ for the Fowler position. Healey et al. (2004) indicated an effect size for two positions, supine with lumbar support at $d = 0.2$ and side lying with spinal flexion at $d = 0.13$. A study by Ahrens (1994) indicated an effect size for the supine position with no support of $d = 0.4$. A power analysis using Gpower Computer program (Faul & Erdfelder, 1998) and SAS Macro Program (http://euclid.psych.yorku.ca/cgi/power.pl), indicated that a sample size of 24 participants would be needed to detect small effects (*d* = 0.25) with 80% power using two, one-way repeated measures ANOVAs with alpha set at .05. Studies assessing the impact of running and spinal shrinkage typically recruited a sample size between seven and 20 participants (Ahrens, 1994; Carigg and Hillemeyer, 1992; Dmitriadis et al., 2011; Dowzer et al., 1998; Garbutt et al., 1989; Garbutt et al., 1990; Kinglsey et al., 2012; Leatt et al., 1986; Reilly et al., 1988). Using a conservative effect size the determined sample size for this study was greater than those used in previous research necessary to determine small effects. Initially, 24 participants were recruited for participation. However, due to attrition associated with scheduling conflicts and unrelated injury or illness, three participants were unable to participate.

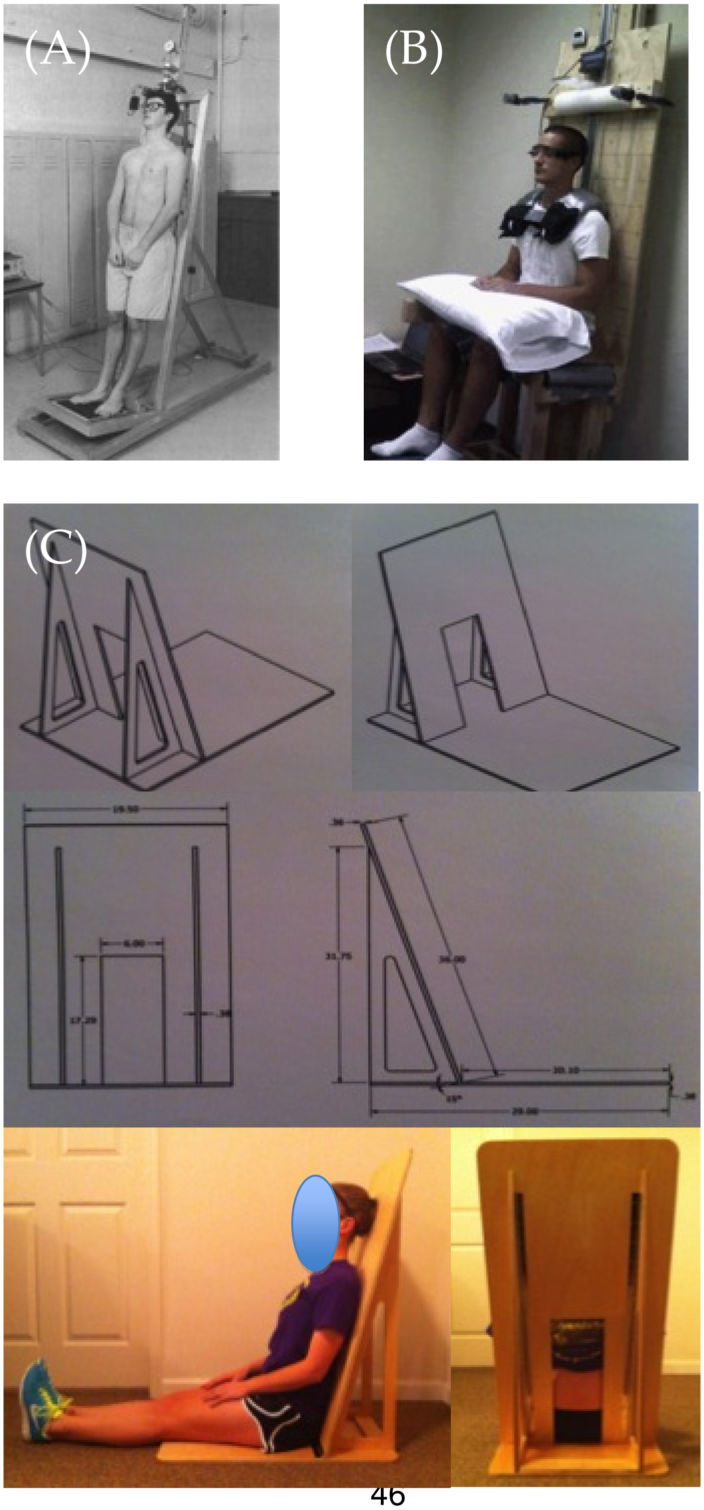
Instrumentation

Running. Running protocols were performed on a Trackmaster TMCX425™ motorized treadmill (Trackmaster Treadmills JAS Fitness Systems, Newton, KS). An incline of 0° was used for all participants. Heart rate was tracked throughout the running protocol using a Polar™ RS800CX© heart rate monitor (Polar Electro Inc., Lake Success, NY).

Spinal unloading. Preceding research has indicated that supine unloading positions immediately yielded significant gains in stature following compressive loading (Healey et al., 2004; Fowler et al., 1994; Fowler et al., 2005; Gerke et al, 2011; Rodacki et al., 2003; Rodacki et al., 2007). Supine positioning removes the influence of gravity while providing postural control. Multiple supine positions previously assessed were used for this study: Fowler position (Dowzer et al., 1998; Rodacki et al., 2007; Wilby et al., 2007), side lying with spinal flexion (Fowler et al., 2005; Gerke et al., 2011; Healey et al., 2004; Rodacki et al., 2003), supine with lumbar support (Healey et al., 2003; Magnussen & Pope, 1996), and supine with no support (Ahrens, 1994; Kanlayanaphotporn et al., 2001). Spinal unloading positions occurred with the participant lying on a commercially-available foam exercise mat measuring 68 inches in length by 24 inches in width and ¼ inch in thickness. A bubble level was used to ensure measurements occurred on a flat, level surface. Additional equipment required for various unloading positions included a plastic chair with a seat height of 18 in for leg support and a foam fulcrum for lumbar support. The 20 min duration of each spinal unloading session was monitored using an ACCUSPLIT® Pro Survivor A601X Stopwatch (Accusplit Inc., Livermore, CA). A plastic goniometer (National Posture Institute, Bastrop, TX) was used to measure hip and knee flexion angles for various positions.

Spinal Shrinkage. Research has determined measurement of overall stature change as a valid method to assess spinal shrinkage (Carigg & Hillemeyer, 1992; Dmitriadis et al., 2011; Dowzer et al., 1998; Fowler et al., 2005; Garbutt et al., 1990; Kingsley et al., 2012; Leatt et al., 1986; Reilly, 2010; Roush et al., 2004; Seay et al., 2008; White & Malone, et al., 1990). A Harpenden© sliding anthropometer and a rigid wooden frame were used as a modified version of the stadiometer described by Boocock et al. (1986) to measure overall changes in length of the spine. The stadiometer allows for precise stature measurements while accommodating for interindividual variations in posture and contours of the spine. Measurements were taken with participants in a relaxed standing position after being reclined 15° from a vertical position. The additional design features of the apparatus allow adjusting for control of head and limb positions. Respiration rate and soft-tissue deformation creep of the lower extremities is controlled by having participants rest against the stadiometer for 1-2 min before measurements are recorded. Ten consecutive measurements are then recorded following full exhalation of the successive ten breaths (see Figure 3(A) (Boocock et al., 1986). Owens et al. (2009) and Kanlayanaphotporn et al. (1994) used a similar stadiometer as previously described with participants in a relaxed, seated position to assess changes in spine length by measuring sitting height. An additional feature used by Kanlayanaphotporn et al. (2001) was an attached ultrasound transducer to measure changes of intervertebral disc height between L5-S1 vertebral bodies (see Figure 3(B)). The wooden frame used for this study featured a flat surface where participants sat with legs extended. Postural control during measurements was achieved by requiring subjects to make contact with their head, shoulder blades, and buttocks with the back portion of the frame. Additionally, the back portion provided a similar relaxed position as the stadiometer by inclining the participant by 15° from a vertical position. Similar to Boocock et al. (1986), respiration rate was controlled for with participants resting against the wooden frame for 1 min. With the sliding anthropometer resting flat against the back portion of the frame, sitting height measurement were taken.

Figure 3. Stadiometer designed by Boocock et al. (1988) to assess Spinal shrinkage (A). Modified stadiometer used by Owens et al. (2009) and Kanlayanaphotporn et al. (1994) measuring spinal shrinkage in seated position (B). Wooden frame modeled after stadiometer in A and B, used for this study to complete sitting height and ultrasound imaging.



Three consecutive measurements occurred upon full exhalation of three subsequent breaths following the respiration control period (see Figure 3(C)).

Radiographic imaging using a Sonosite© Micromaxx™ diagnostic ultrasound with a C60E/5-2 MHz™ transducer (SonositeInc., Bothell, WA) were used to measure changes in IVD height. Although the ultrasound does not provide direct imaging of the IVD as an MRI does, the transducer had a penetration depth of 11.5 cm, allowing axial and lateral views of the vertebral bodies and IVD space. Several studies have validated the precision of using a diagnostic ultrasound to measure IVD height through changes in the distance between the transverse process of the vertebral bodies (Carigg & Hillemeyer, 1992; Dmitriadis et al., 2011; Kadziolka et al., 1981; Kingsley et al., 2012; Ledsome et al., 1996; Naish et al., 2003; Shao et al., 2002). The process to measure the IVD height via the space between the transverse processes is similar to ultrasound-guided injections for epidurals, nerve blocks, and anesthesia. By placing the transducer in a longitudinal position 4 cm lateral to the midline of the spine, a paramedian sagittal view of the transverse processes can be achieved (see Figure 4(A)) (Chin, 2012; Karmakar et al., 2009; Loizides et al., 2011). The transverse processes appear upon the ultrasound screen as short hyperechoic curvilinear structures with finger-like shadowing extending below. This is also described as looking similar to the prongs of a trident (see Figure 4(B)) (Chin, 2012; Karmakar et al., 2009; Ledsome et al., 1996; Loizides et al., 2011).

The proficiency of the researcher was achieved by assessing inter- and intra-tester reproducibility of measurement as described by Ledsome et al. (1996). Distances were measured between the transverse processes of the lumbar vertebrae (L5) and

Figure 4. Placement of the transducer head for a paramedian sagittal view of the transverse processes (A) and corresponding ultrasound image of the lumbar spine (B). The transverse processes in the ultrasound image are labeled with TP.

sacrum (S1) for one participant on five separate occasions by two expert observers. Each observer performed three measurements between the tips of transverse process of vertebral bodies. Means and standard deviations were calculated for each measurement set on each occasion. Coefficient of variation was calculated to compare the degree of variation from one observer to another, in addition to the consistency of the researcher between measurement sessions. Ledsome et al. (1996) reported a coefficient of variation of ± 4% between observers and measurement periods and was used as the standard for proficiency within this study.

Procedures

Familiarization and introduction. Data collection occurred over the course of five days, including one day of familiarization and four days for experimental sessions. The time each experimental session was conducted was strictly controlled, as it is understood that spinal height fluctuates according to circadian variation (Ledsome et al., 1996; Tyrrell et al., 1985; Van Deursen et al., 1995). Each experimental session occurred with no less than 24 hours between each session and conducted within the same two-hour time frame each day. On the first day of participation, signed consent forms were collected detailing each participant's demographic information, injury history, running history, and acknowledgement of potential risks. Further instruction was given to participants concerning the importance of wearing appropriate athletic attire, wearing the same footwear, and not engaging in additional physical activity beyond those of daily living on data collection days. A period of familiarization involving an introduction to running intervention, unloading positions, and measurement procedures followed.

Participants were instructed on how to apply a chest strap heart rate monitor and wristwatch receiver. Resting heart rate was recorded and age-predicted maximum heart rate calculated (220 – age). Participants then completed a modified running protocol on a motorized treadmill. Self-selected pace was determined using a protocol described by Vehrs et al. (2007). Participants began walking on the treadmill at a speed of 3.0 mph. Speed was then increased once every 60 sec by 0.5 mph, until the participant's comfortable pace was achieved and maintained for an additional 5 min. The corresponding treadmill speed was recorded for use on subsequent data collection days.

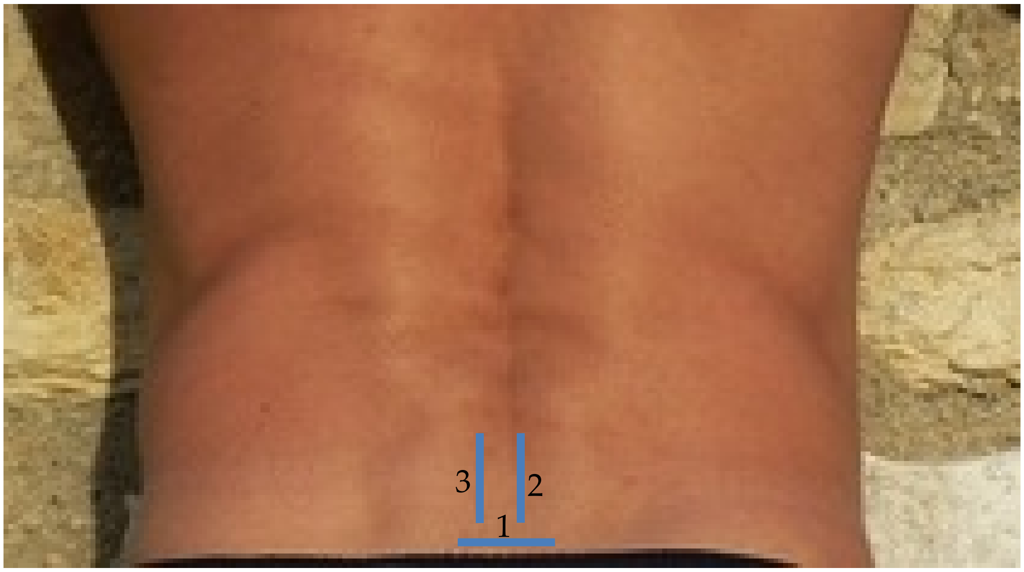
To control for learning and order affects, participants did not physically perform any of the spinal unloading positions during the familiarization day. Researchers verbally described the various spinal unloading positions to the participants in addition to the process used for random assignment of unloading positions each data collection day. Random assignment of unloading positions was achieved by assigning each position a number one through four. Numbers were written on paper and concealed in a container. Each day, before the start of the first spinal unloading period, the researcher blindly selected a number and participants performed the corresponding position.

To measure IVD height, researchers palpated the fifth lumbar vertebra (L5) and the midline of the spine (Beil, 1997). Using a permanent ink pen and ruler these locations were marked on the skin. With the participant in a seated position resting against the wooden frame, researcher measured with a ruler 4 cm lateral to the midline spine. By placing the transducer in a longitudinal position, a paramedian sagittal view of the transverse processes appeared (Chin, 2012; Karmakar et al., 2011; Ledsome et al., 1996; Loizides et al., 2011). Using the ruler and permanent ink pen, this location was marked for placement of the transducer on subsequent data collection days. The participant remained in the seated position while the researcher described and performed one seated height measurement. See Figure 5 for locations of each marking upon the skin.

Experimental protocol. Experimental protocols from prior studies assessing running and spinal shrinkage were used and adapted for this study (Dowzer et al., 1997; Garbutt et al., 1989; Kingsley et al., 2012; White & Malone, 1990). All data collection occurred in the EWU Health Sciences Biomechanics Laboratory (EWU Riverpoint Campus, Spokane, WA). Before beginning the experimental protocol, a heart rate monitor was applied. Markings for the L5 vertebrae, in addition to location for placement of the transducer, were checked and reapplied if necessary. To account for effects of circadian variation and activities of daily living, initial sitting and IVD height measurements were recorded. Following initial measurements, participants performed one of the four randomly selected unloading positions for 20 min (Fowler position, side lying with spinal flexion, supine with lumbar support, and supine with no support) (see Figure 2).

Fowler position. Participants were instructed to lie in a supine position on an exercise mat with legs elevated at 45°. Legs were supported with a plastic chair resting against a rigid wall. Feet were shoulder width apart and ankles dorsiflexed. Arms were

Figure 5. Markings made on the skin to identify anatomical landmarks of the lumbar spine including (1) the fifth lumbar vertebra (L5), (2) the midline of the spine, and (3) the placement for the transducer head.



extended to the side of the body, resting upon the floor. A plastic goniometer was used to ensure hip and knee flexion angles remained at 45° (see Figure 2 [A]) (Dowzer et al., 1998; Rodacki et al., 2007; Wilby et al., 2007).

Side lying with spinal flexion. Participants were instructed to lie on their side with hips and knees flexed to 90°. Arms crossed the chest with hands resting upon opposing arms. A plastic goniometer was used to ensure correct hip and knee flexion angles (see Figure 2 [B]) (Fowler et al., 2005; Gerke et al., 2011; Healey et al., 2004; Rodacki et al., 2003).

Supine with lumbar support. The participant was instructed to sit on an exercise mat with legs fully extended. Feet were shoulder width apart and ankles dorsiflexed. As they began to lie back, a foam fulcrum was be placed under the lumbar region of their spine. Once in a supine position, arms were extended to the side of the body, resting upon the floor (see Figure 2 [C]) (Healey et al., 2003; Magnussen & Pope, 1996; Owens et al., 2009).

Supine with no support. The participant was instructed to lie in a supine position on an exercise mat with legs fully extended. Feet were shoulder width apart and ankles dorsiflexed. Arms were extended to the side of the body, resting upon the floor (see Figure 2 [D]) (Ahrens, 1994; Kanlayanaphotporn et al., 2001).

Upon the conclusion of the unloading period, a second series of sitting and IVD height measurements were recorded to account for any spinal loading that may have occurred prior to the start of experimental session and to serve as baseline measurements for that day. The participant then ran on a Trackmaster TMX425C™ motorized treadmill at an incline of 0° and constant speed, as previously determined on the familiarization day. The duration of the running protocol was 20 min, including a 5 min warm-up and 15 min run. Previous research indicates that the initial 15 min interval of a run is when the greatest amount of spinal shrinkage will occur, with little to no shrinkage occurring when a second 15 min interval run was performed (Dowzer et al., 1997; Garbutt et al., 1989; Kingsley et al., 2012; White & Malone, 1990). Heart rate was recorded every 3 min using a Polar© RS800CX™ heart rate monitor to maintain a similar exercise intensity each data collection session. Upon the completion of the 15 min run, a third series of sitting stature and IVD height measurements were recorded to quantify the amount of spinal shrinkage that occurred as a result of running. Participants performed another 20 min period of spinal unloading in the same position randomly selected at the start of the data collection session, followed by a fourth series of sitting and IVD height measurements.

Measurement protocol. Sitting height measurements were used to assess changes in length of the spine. Participants sat with head, shoulder blades, and buttocks in contact with a rigid wooden frame. Legs were extended with hands resting on the thigh and the head aligned in the Frankfort plane (Norton & Olds, 1996). Measurements were taken using a Harpenden© sliding anthropometer. Additionally, a bubble level was used to ensure measurements were taken from a flat, level surface. For each measurement period, the participant was instructed to take five breaths to control for respiration rate. Following the fifth exhalation, the arm of the anthropometer was lowered to a final position resting upon their head and a measurement was recorded. This was repeated following two additional breaths, with the arm of the anthropometer being repositioned for each measurement. A total of three measurements were recorded for each measurement period.

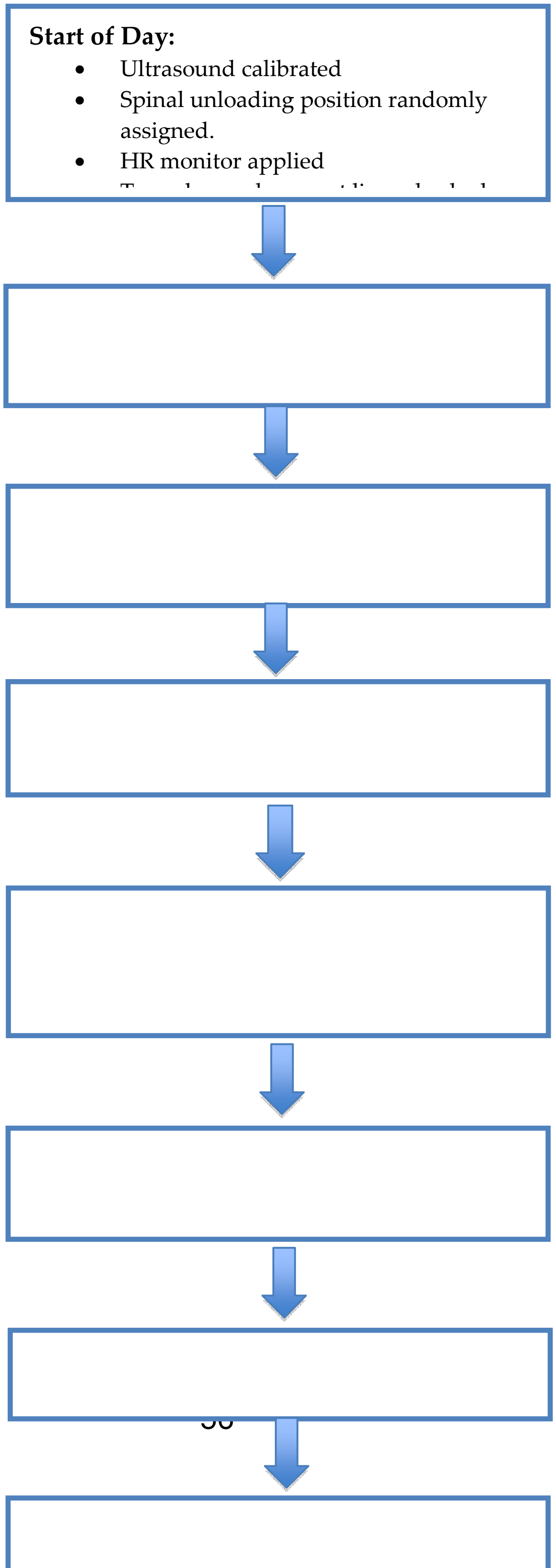
Intervertebral disc height measurements were completed using a Sonosite© Micromaxx™ diagnostic ultrasound with a C60E/5-2 MHz™ transducer. Measurements were taken with participants in a seated position as previously described. The diagnostic ultrasound was calibrated according to the manufacturer's recommendations at the start of each data collection session (Micromaxx Ultrasound System Service Manual, 2005). Briefly, calibration was achieved by placing the transducer longitudinally along a pre-designated line lateral to the midline of the spine to assess image quality and measurement accuracy for paramedian sagittal views of the lumbar vertebrae. Two-dimensional, real-time imaging was displayed from which three static images were taken. Distance measurements were performed by positioning electronic calipers in the center of the shadow produced by the tip of each transverse process; a corresponding distance measurement was displayed upon the screen of the ultrasound (Ledsome et al., 1996; Micromaxx Ultrasound System User Guide, 2008). An overview outlining the sequence of events for each data collection session is highlighted in Figure 6.

Statistical Analysis

Statistical Package for Social Sciences Version 20.0 (SPSS Inc., Chicago, IL) was used to perform all descriptive and inferential statistical computations.

Ultrasound static image and sitting height measurements following each position, for each participant

Figure 6. Overview of the experimental protocol for each data collection session.



were averaged across the three measurement trials per measurement period. Means and standard deviations were calculated for each spinal unloading position to assess differences in sitting and IVD height measurements between pre-run, post-run, and post unloading measurement periods.

A Cronbach's Alpha was performed as a measure of internal reliability across the three measurement trials per measurement period for each position and condition. Paired-samples t-tests were conducted to assess the independent effectiveness of each unloading position in recovering from spinal shrinkage. Two repeated measures, one-way ANOVAs were used to determine if a statistically significant difference existed in recovery from spinal shrinkage between each of the four unloading positions assessed. In the event that significance was found, post hoc analyses were performed to identify which unloading positions differed.

Chapter 4

Results

Introduction

The purpose of this study was to assess the immediate effectiveness of four different supine spinal unloading positions in recovering from lumbar spinal shrinkage incurred while running among recreational runners. This research sought to determine if a statistically significant difference would occur between four different supine position conditions: relaxed supine, Fowler position, side lying with spinal flexion, and supine with lumbar support. This chapter reviews the statistical analyses used to assess these data and corresponding results.

Demographics

Participants for this study were composed of a convenience sample including 21 undergraduate students (female *n* = 13, male *n* = 8) from Eastern Washington University in Cheney, Washington. Descriptive data for participant demographics are listed in Table 1.

Table 1.

Participant Demographics

Characteristic	*M*	*SD*
Age	23.04	1.90
Height	169.40	7.36
Weight	153.20	28.20
Run Frequency	2.90	1.07
Run Duration	29.00	11.10

Note. N = 21, Age = years, Height = cm, Weight = kg, Run Frequency = per week, Run Duration = min.

Descriptive Statistics

Changes in IVD and sitting height were recorded during four measurement periods: initial, post unload 1, post run, and post unload 2. A series of three measurement trials were conducted per measurement period. Prior to conducting descriptive analyses, a Cronbach's Alpha was conducted to assess the internal consistency and reliability across measurement trials for each measurement period. Results indicate excellent internal consistency, reporting reliability coefficients greater than 0.9 among three trials within all measurement periods and unloading positions for IVD and sitting height measurements. Averages for each participant's IVD and sitting height measurements were calculated across the 3 trials per period and unloading position. Group means, standard deviations (Table 2-3), and stature changes (Tables 4-5) for IVD height and sitting height were calculated and reported for each position. Overall, each participant exhibited recovery from spinal shrinkage after the second unloading protocol. The greatest recovery in IVD height occurred after the supine position with lumbar support (ST CH = + 0.34 cm; % CH = + 12.88%), in comparison to the Fowler position, which yielded the greatest recovery for sitting height (ST CH = + 8.71 cm; % CH = + 1.12%).

Table 2.

Group Means and Standard Deviations for Intervertebral Disc Height Measurements

Position	Initial	Post Unload 1	Post Run	Post Unload 2
Relaxed Supine	3.18 ± 0.34	3.37 ± 0.37	3.07 ± 0.29	3.36 ± 0.31
Fowler	3.21 ± 0.16	3.32 ± 0.18	3.06 ± 0.21	3.34 ± 0.19
Side Lying	3.12 ± 0.23	3.31 ± 0.23	3.09 ± 0.22	3.38 ± 0.22
Lumbar Support	3.15 ± 0.23	3.36 ± 0.24	3.06 ± 0.24	3.41 ± 0.26

Note. Intervertebral disc height measurement units = cm

Table 3.

Group Means and Standard Deviations for Sitting Height Measurements

Position	Initial	Post Unload 1	Post Run	Post Unload 2
Relaxed Supine	849.01 ± 38.80	852.06 ± 39.20	843.00 ± 38.50	850.00 ± 38.00
Fowler	848.80 ± 39.20	852.30 ± 39.30	843.40 ± 38.06	852.80 ± 37.70
Side Lying	850.70 ± 38.20	853.50 ± 37.50	845.40 ± 36.80	851.60 ± 36.90
Lumbar Support	849.20 ± 39.10	854.10 ± 36.60	846.00 ± 37.00	854.40 ± 37.90

Note. Sitting height measurement units = mm.

Table 4.

Group Calculated Means and Standard Deviations for Stature Change and Percent Change for IVD Height (cm) Between Measurement Periods

	M1-M2		M2-M3		M3-M4	
Position	*ST CH*	*% CH*	*ST CH*	*% CH*	*ST CH*	*% CH*
Relaxed Supine	0.19 ± 0.15	6.19%	-0.30 ± 0.17	-9.01%	0.28 ± 0.16	9.30%
Fowler	0.11 ± 0.11	3.47%	-0.25 ± 0.10	-7.80%	0.27 ± 0.12	8.82%
Side Lying	0.19 ± 0.20	6.16%	-0.22 ± 0.08	-6.84%	0.29 ± 0.12	9.49%
Lumbar Support	0.21 ± 0.10	6.87%	-0.30 ± 0.15	-9.08%	0.34 ± 0.13	12.88%

Note. M1-M2 = initial to post unload 1; M2-M3 = post unload 1 to post run; M3-M4 = post run to post unload 2; ST CH = stature change; % CH = % stature change.

Table 5.

Group Calculated Means and Standard Deviations for Stature Change and Percent Change for Sitting Height (mm) Between Measurement Periods

	M1-M2		M2-M3		M3-M4	
Position	*ST CH*	*% CH*	*ST CH*	*% CH*	*ST CH*	*% CH*
Relaxed Supine	3.04 ± 3.83	0.36%	-9.06 ± 3.72	-1.06%	6.93 ± 2.57	0.99%
Fowler	3.49 ± 2.77	0.41%	-8.49 ± 2.54	-1.05%	8.71 ± 2.60	1.12%
Side Lying	2.70 ± 3.44	0.32%	-8.09 ± 4.55	-0.95%	6.50 ± 3.00	0.85%
Lumbar Support	4.90 ± 3.90	0.59%	-8.10 ± 3.20	-0.96%	8.40 ± 2.80	1.00%

Note. M1-M2 = initial to post unload 1; M2-M3 = post unload 1 to post run; M3-M4 = post run to post unload 2; ST CH = stature change; % CH = % stature change.

To evaluate data for a normal distribution, the Shapiro-Wilk test was conducted along with assessment of skewness and kurtosis of the data. Data evaluated included mean measurement values for post run and post unload 2 periods for each position and condition. The Shapiro-Wilk test reported all significance values exceeding 0.05, indicating all data were normally distributed. Analysis of skewness and kurtosis was conducted by dividing the statistic value by its standard error. No significant difference ($p > 0.05$) from a normal distribution was found for all variables as none of the values exceeded ± 1.97.

Recovery measurements from spinal shrinkage (calculated stature change M3-M4) per position and condition were also assessed for a normal distribution. The Shapiro-Wilk test reported all significance values exceeding 0.05, indicating all data were normally distributed. Assessment of skewness and kurtosis also revealed that the data distributions were not significantly different from a normal distribution, as calculated values did not exceed ± 1.97 for all variables.

Heart rate for each participant was monitored during the running protocol (every 3 min) for each data collection session. Resting heart rate (RHR) and age were included to calculate age-predicted maximum heart rate (MHR) using the Karvonen formula. Heart rate recordings were averaged for each data collection session to monitor the exercise intensity of each participant. Overall, results indicate that participants maintained a similar level of intensity (% MHR) over the course of four data collection sessions (see Table 6).

Table 6.

Summary of Participant Heart Rate and Intensity Information

Participant	RHR	MHR	AvgHR	AvgInt
1	70	197	192	96
2	71	196	130	66
3	67	197	157	79
4	66	198	153	77
5	58	195	157	80
6	67	196	185	94
7	70	199	163	82
8	52	196	170	86
9	68	196	146	74
10	69	195	164	84
11	66	196	163	83
12	53	198	143	72
13	66	199	164	82
14	80	197	158	80
15	68	199	175	88
16	76	198	185	93
17	70	197	173	88
18	58	191	157	82
19	69	200	165	82
20	72	198	163	82
21	70	198	159	80

Note. RHR = Resting Heart Rate; MHR = Age-Predicted Maximum Heart Rate; AvgHR = Average Heart Rate; AvgInt = % of MHR.

Paired-Samples t-tests

Prior to testing the research hypothesis, paired-samples t-tests were conducted to determine the independent effectiveness of each unloading position in recovering from spinal shrinkage for both IVD and sitting height. Calculated mean measurements from following the running protocol were compared to those following the second unloading session for each position. Statistically significant increases ($p < 0.05$) in IVD height (Table 7) and sitting height (Table 8) measurements were observed for all positions. No adjustment for multiple comparisons was used.

Table 7.

Paired Samples t-test Outcome Comparing Post Run and Post Spinal Unload 2 for IVD Height (cm) Measurements

	Post Run	Post Unload 2				
Position	*M* ± *SD*	*M* ± *SD*	*95% CI*	*df*	$\square^2$	*p*
Relaxed Supine	3.07 ± 0.29	3.36 ± 0.31	[-.35, -.21]	20	0.87	< 0.001
Fowler	3.06 ± 0.21	3.34 ± 0.19	[-.32, -.21]	20	0.91	< 0.001
Side Lying	3.09 ± 0.22	3.38 ± 0.22	[-.35, -.23]	20	0.92	< 0.001
Lumbar Support	3.06 ± 0.24	3.41 ± 0.26	[-.28, -.40]	20	0.93	< 0.001

Note. CI = confidence interval; $\square^2$ *= effect size.*

Table 8.

Paired Samples t-test Outcome Comparing Post Run and Post Spinal Unload 2 for Sitting Height (mm) Measurements

	Post Run	Post Unload 2				
Position	*M* ± *SD*	*M* ± *SD*	*95% CI*	*df*	$\square^2$	*p*
Relaxed Supine	843.00 ± 38.50	850.00 ± 38.00	[.56, -8.1]	20	0.94	< 0.001
Fowler	843.40 ± 38.06	852.80 ± 37.70	[.56, -9.8]	20	0.95	< 0.001
Side Lying	845.40 ± 36.80	851.60 ± 36.90	[.65, -7.8]	20	0.91	< 0.001
Lumbar Support	846.00 ± 37.00	854.40 ± 37.90	[.61, -9.6]	20	0.95	< 0.001

Note. CI = confidence interval; $\square^2$ *= effect size.*

One-Way ANOVAs

Repeated measures one-way ANOVAs were conducted to evaluate the research hypothesis. Mean values for recovery from spinal shrinkage were represented by a calculated stature change between post run and post unload 2 measurement periods for both IVD and sitting height. The one-way ANOVAs were used in conjunction with a Bonferroni adjustment to determine if a significant difference in recovery from spinal shrinkage existed between positions. Post-hoc analyses were employed to reveal which of the unloading positions yielded a greater recovery amount than the others. This analysis revealed a statistically significant difference ($p < 0.05$) in the amount of recovery from spinal shrinkage between positions for sitting height measurements (Table 9). However, post-hoc analyses further revealed no significant difference between unloading positions as all significance values were greater than 0.05. In contrast, there was no statistically significant difference ($p > 0.05$) in the amount of recovery from spinal shrinkage between positions for IVD height measurements (Table 10).

Table 9.

Repeated Measures One-Way ANOVA Summary Table Comparing Recovery from Spinal Shrinkage for Sitting Stature

Source	*df*	*SS*	*MS*	*F*	*P*	□*2*
Between-group	1	7.5	7.5	271.4	0.017	0.15
Within-group	3	0.071	0.024	1.4		
Total	4	7.571				

Note. □*2 = effect size.*

Table 10.

Repeated Measures One-Way ANOVA Summary Table Comparing Recovery from Spinal Shrinkage for IVD Height

Source	*df*	*SS*	*MS*	*F*	*P*	□*2*
Between-group	1	4901	4901.1	474.2	0.226	0.07
Within-group	3	73.5	24.5	3.6		
Total	4	4975				

Note. Note. □*2 = effect size.*

Chapter 5

Discussion

Introduction

The objective of the current study was to assess the immediate effectiveness of the supine spinal unloading positions in recovering from spinal shrinkage incurred while running among a group of recreational runners. This research sought to determine if a significant difference in recovery would occur between four different supine spinal unloading positions, including: Fowler position, side lying with spinal flexion, supine with lumbar support, and relaxed supine. The following chapter will interpret the results from statistical analyses, relate findings with previous literature, as well as discuss directions for future research.

Recovery Effectiveness

Assessing the effectiveness of each unloading position in recovering from spinal shrinkage independently was not part of the initial hypothesis for this study. Extensive literature demonstrates that each of the four supine unloading positions is effective independently in recovering from spinal shrinkage as measured by changes in overall stature (Dowzer et al., 1997; Fowler et al., 2005; Gerke et al., 2011; Healey et al., 2004; Kanlayanaphotporn et al., 2001; Magnussen & Pope, 1997; Owens et al., 2009; Rodacki et al., 2003; Rodacki et al., 2007; Wilby et al., 2007). Limited research, however, is available regarding the use of radiographic imaging to assess this. Currently only two studies have demonstrated the effectiveness of two different supine spinal unloading positions in recovering from spinal shrinkage as measured by IVD height using diagnostic ultrasound imaging (Kanlayanaphotporn et al., 2001; Owens et al., 2009). Therefore before a comparison could be made between unloading positions, it was necessary to determine whether the recovery for each supine spinal unloading position was statistically significant for IVD height and sitting stature.

Sitting stature. In the present study, paired-samples t-tests were used to determine if each supine unloading position yielded a significant increase in sitting stature. Mean measurements recorded after the running protocol were compared with measurements recorded after a second unloading session for each supine position. Researchers observed statistically significant increases in stature after the second unloading position for each supine position (Table 6). These findings are consistent with previous research in which participants exhibited gains in stature following a 20 min period of spinal unloading in each of the four supine positions assessed (Dowzer et al., 1997; Fowler et al., 2005; Gerke et al., 2011; Healey et al., 2004; Kanlayanaphotporn et al., 2001; Magnussen & Pope, 1997; Owens et al., 2009; Rodacki et al., 2003; Rodacki et al., 2007; Wilby et al., 2007). Overall results suggest that manipulating the body in a supine position yields significant immediate benefits in recovering from spinal shrinkage. Effective recovery is attributed to the assumption that manipulating the body in a supine position removes the compressive force acting on the IVD by reducing the effects of gravity, thus promoting elongation of the spine (Garbutt et al., 1990).

Further analysis of the data revealed differences in the amount of recovery reported from the current study in comparison to previous research. Prior studies report relatively small amounts of recovery across all supine positions ranging between two to four mm following a period of supine spinal unloading (Dowzer et al., 1997; Fowler et al., 2005; Gerke et al., 2011; Healey et al., 2004; Kanlayanaphotporn et al., 2001; Magnussen & Pope, 1997; Owens et al., 2009; Rodacki et al., 2003; Rodacki et al., 2007; Wilby et al., 2007). As seen in Table 5, values reported from the current study for recovery are considerably larger ranging between 6.93 mm (± 2.57 mm) and 8.71 mm (± 2.60 mm) following the second spinal unloading session across all supine unloading positions. These differences in measurement values are attributed to several factors associated with experimental design.

The sequence of events for each data collection session is one factor which may have influenced the difference in the recovery values observed in the current study in comparison to previous research. The current study required participants to perform two periods of spinal unloading during each experimental session. One spinal unloading period was performed at the start of the experimental session, whereas the second unloading period was performed after the running protocol. The initial unloading session accounted for any spinal shrinkage that occurred due to circadian variation and activities of daily living. Research assessing spinal shrinkage and running employs a spinal unloading technique before and after the experimental protocol to control for stature loss due to circadian variation and activities of daily living (Ahrens, 1994; Carigg &

Hillemeyer, 1992; Dowzer et al., 1998; Garbutt et al., 1990; Kingsley et al., 2012; Leatt et al., 1986; Seay et al., 2008). Others have controlled for this potential variation in stature by completing all experimental protocol within the same time frame each day (Dmitriadis et al., 2011; Roush et al., 2004; White & Malone, 1990). Currently, only two studies assessing the effectiveness of spinal unloading positions in immediately recovering from spinal shrinkage have employed an unloading position before and after experimental protocol (Dowzer et al., 1998; Garbutt et al., 1990). Values reported for spinal shrinkage and recovery are greater in studies which implemented an unloading position before and after experimental protocol (Dowzer et al., 1998; Garbutt et al., 1990). These higher values for spinal shrinkage and recovery are attributed to the relative hydration of the IVD at the start of the experimental session. It has been observed that the relative hydration level of the IVDs directly impacts the viscoelastic properties of the IVD and thus mechanical response to imposed loads (Broberg, 1993; Haher et al., 1993; Nachemson, 1976; Roaf, 1960; White & Panjabi, 1990). For example, previous experimental protocols involved participants completing two 15 min interval runs (Dowzer et al., 1997; Garbutt et al., 1989; Kinglsey et al., 2012; Roush et al., 2004; White & Malone, 1990). Results consistently demonstrated that the greatest amount of shrinkage occurred within the first 15 min interval run, with little to no shrinkage observed in the second 15 min interval run (Dowzer et al., 1997; Garbutt et al., 1989; Kinglsey et al., 2012; Roush et al., 2004; White & Malone, 1990). It is assumed that IVDs exhibited greater hydration at the start of the running protocol, resulting in greater amounts of shrinkage.

Stature measurement procedure is an additional experimental design factor that may have contributed to the difference in reported values for observed stature changes. Preceding studies have measured spinal shrinkage and recovery from spinal shrinkage by measuring changes in stature (Dowzer et al., 1997; Fowler et al., 2005; Gerke et al., 2011; Healey et al., 2004; Kanlayanaphotporn et al., 2001; Magnussen & Pope, 1997; Owens et al., 2009; Rodacki et al., 2003; Rodacki et al., 2007; Wilby et al., 2007). A stadiometer, as originally described by Boocock et al. (1986) was the standard measurement tool used for assessing changes in standing stature. Although this device demonstrated excellent measurement precision (0.01 ± 0.005 mm), it only provided measurements in overall stature with no distinction between changes in the spine versus the lower extremities. Subsequent studies modified this stadiometer to measure changes in sitting stature to isolate and observe change in stature specifically within the spine (Kanlayanaphotporn et al., 2001; Owens et al., 2009). Similarly, the current study recorded measurements of sitting stature. The greater values for recovery are in agreement with previous research measuring stature changes with participants in a seated position (Kanlayanaphotporn et al., 2001; Owens et al., 2009).

Intervertebral disc height. In the present study, paired-samples t-tests were used to determine if each supine unloading position yielded a significant increase in IVD height. Mean measurements recorded after the running protocol were compared with measurements recorded after a second unloading session for each supine position. Researchers observed statistically significant increases in IVD height after the second unloading position for each supine position (Table 7). These results are in agreement with previous research. Kanlayanaphotporn et al. (2001) used ultrasound imaging to assess the ability of the L5-S1 IVD to recover from spinal shrinkage following a 20 min period of spinal unloading in the Fowler position. Results indicated a significant increase in IVD height of 1.25 mm (± 2.18 mm). Similarly, Owens et al. (2009) compared the effectiveness of two supine unloading positions, including Fowler position and supine with a lumbar support. Intervertebral disc height measurements of the L5-S1 IVD were recorded using ultrasound imaging. Results indicated a significant increase in IVD of 3.1 mm (± 2.8 mm) for the Fowler position and 3.19 mm (± 3.00 mm) for lying supine with a lumbar support (Owens et al., 2009). Numerous studies have validated the use of diagnostic ultrasound as the a valid method to assess the mechanical behavior of the IVDs (Carigg & Hillemeyer, 1992; Dmitriadis et al., 2011; Kadziolka et al., 1981; Kanlayanaphotporn et al., 2001; Kingsley et al., 2012; Ledsome et al., 1996; Naish et al., 2003; Owens et al., 2009; Shao et al., 2002). The application of this technology in assessing spinal shrinkage and the ability of the IVD to recover from spinal shrinkage is limited (Kanlayanaphotporn et al., 2001; Owens et al., 2001). Currently, no data exists beyond the current study assessing the effectiveness of side lying with spinal flexion and relaxed supine positions using radiographic imaging. However, as with sitting stature, overall results suggest that manipulating the body in a supine position yields significant immediate benefits in recovering from spinal shrinkage.

Recovery Effectiveness Comparison

The primary purpose of this study was to determine if a statistically significant difference would occur in the amount of recovery between four supine spinal unloading positions. Two, repeated-measures one-way ANOVAs in conjunction with a Bonferroni adjustment were conducted to evaluate the research hypothesis. Mean values for recovery were represented by a calculated change in IVD height and sitting stature between post run and post the second unloading measurement periods. Post-hoc analyses were employed to reveal which of the unloading positions yielded a greater recovery amount than the others. These analyses revealed no statistically significant difference ($p > 0.05$) in the amount of recovery from spinal shrinkage between positions for the IVD height measurements (Table 8). Conversely, these analyses revealed a statistically significant difference ($p < 0.05$) in the amount of recovery from spinal shrinkage between positions for sitting stature measurements. However, post-hoc analyses further revealed no statistically significant difference in the amount of recovery from spinal shrinkage between the four supine unloading positions as all significance values were greater than 0.05. A power analysis conducted prior to the current study indicated statistical power of 0.8 and an effect size of $d = 0.25$ would be required in order to detect small effects. The current study did not meet these minimum requirements, reporting statistical power of 0.78 and an effect size of 0.15 (Table 9).

Although there was no statistically significant difference detected for either sitting stature or IVD height, an analysis of the raw data suggested that one unloading position may yield greater immediate effectiveness in recovering from spinal shrinkage than the others. The position identified as producing the greatest recovery differed between sitting stature and IVD height measurement data sets. Results from the present study indicate the Fowler position as the most effective unloading position in recovering from spinal shrinkage for sitting stature (+ 8.71 mm ± 2.6 mm; + 1.12%). These results contradict previous literature that indicates side lying with spinal flexion elicits greater amounts of recovery than relaxed supine, lying supine with a lumbar support, or the Fowler positions. Again, differences are attributed to several factors associated with experimental design. Foremost, the majority of studies assessing the effectiveness of spinal unloading positions in recovering from spinal shrinkage measured stature changes with participants in a standing position (Dowzer et al., 1997; Fowler et al., 2005; Gerke et al., 2011; Healey et al., 2004; Kanlayanaphotporn et al., 2001; Magnussen & Pope, 1997; Owens et al., 2009; Rodacki et al., 2003; Rodacki et al., 2007; Wilby et al., 2007). The current study, however, measured all stature changes with participants in a seated position similar to Kanlayanaphotporn et al. (2001) and Owens et al. (2009). Additionally, sample population utilized in the different studies varied to include individuals with low-back pain (Rodacki et al., 2003; Rodacki et al., 2007). The musculoskeletal health of the spine impacts the viscoelastic properties of the IVD, which directly influences the amount of observed spinal shrinkage and recovery. Finally, only three studies have compared the effectiveness of multiple supine spinal unloading positions within one study (Gerke et al., 2011; Healey et al., 2004; Owens et al., 2009). Therefore subsequent research is necessary to determine if these results are consistent.

Data from the current study suggests that lying supine with a lumbar support provided the greatest immediate recovery from spinal shrinkage for IVD height (+ 0.34 ± 0.13 cm; + 12.88%) than the other supine unloading positions. These findings are in agreement with a study by Owens et al. (2009) in which lying supine with a lumbar support resulted in greater recovery (+ 3.19 ± 3 mm) than the Fowler position (+ 3.1 ± 2.8 mm). However, only two studies have used ultrasound imaging to assess the effectiveness of supine spinal unloading positions in recovering from spinal shrinkage. The second study by Kanlayanaphotporn et al. (2001) only assessed the effectiveness of the Fowler position reporting an increase in IVD height of 1.25 ± 2.18 mm following a 20 min period of spinal unloading. Although values reported in the present study for lying supine with a lumbar support are greater than those reported by Kanlayanaphotporn et al. (2001) for the Fowler position, further research is necessary. Presently, no data exists assessing the effectiveness of side lying with spinal flexion or a relaxed supine position using ultrasound imaging.

The identification of two different supine unloading positions as yielding the greatest amount of immediate recovery from spinal shrinkage is attributed to the potential mechanical strain placed on the IVD due to the unloading position itself. For example, hip flexion and elevation of the legs as in the Fowler position causes a posterior pelvic tilt, which reduces lumbar lordosis. The straightening of the lumbar spine imposes a compressive force on the IVD and thus inhibits the ability of the disc to fully recover (Broberg, 1993; Nachemson, 1976; White & Panjabi, 1990). In contrast, lying supine with a lumbar support increases the lordotic curvature in the lumbar spine. Hyperextension of the lumbar spine causes a tensile force which elongates the IVD improving its ability to recover (Broberg, 1993; Nachemson, 1976; White & Panjabi, 1990).

Future Research

Future research should consider utilizing a more diverse sample population. Previous research assessing spinal shrinkage and running have primarily used competitive or elite, young male runners without clinical pathologies in the spine (Ahrens, 1994; Carrigg & Hillemeyer, 1992; Garbutt et al., 1990; Leatt et al., 1986; Roush et al., 2004; White & Malone, 1990). Similarly, the current study was delimited to the use of a convenience sample composed of young, healthy male and female recreational runners without musculoskeletal pathologies in the spine. Therefore, results may be limited in their application and may not reflect the potential effects of age and clinical pathologies. Studies have included populations such as those with low-back pain and pregnant women when assessing the effectiveness of spinal unloading positions in recovering from spinal shrinkage (Rodacki et al., 2003; Rodacki et al., 2007). Collectively, these studies demonstrated that clinical populations exhibited significant recovery from spinal shrinkage following a period of spinal unloading in a supine position, but that their recovery was significantly lower in comparison to control groups (Rodacki et al., 2003; Rodacki et al., 2007). Experimental protocol for these studies assessed spinal unloading positions after static loading or activities of daily living. No assessment of spinal unloading positions following a physical activity, such as running has included a clinical population. The inclusion of a clinical population such as individuals with low-back pain within the sample population would allow for a greater understanding of the clinical implications of spinal unloading.

Subsequent research should consider controlling for interparticipant variability. The current study controlled for intraparticipant variability requiring participants to wear the same footwear and perform the running protocol at the same intensity during each experimental session. However interparticipant variability still occurred due to the inability to control for all participants wearing the same brand and model of footwear. Interparticipant variability also occurred due to the inability to control for running mechanics, such as footstrike pattern. Research indicates that the aforementioned factors directly impact the amount of GRF absorbed by the body while running (Cavanaugh, 1990; Novacheck, 1997). A heel strike pattern while running results in a significantly greater amount of GRF absorbed by the body than midfoot or forefoot strike patterns (Cavanaugh, 1990; Novacheck, 1997). Likewise, barefoot or minimalist footwear produce significantly greater amounts of GRF absorbed by the body than shod footwear (Cavanaugh, 1990; Novacheck, 1997). Presently no study has sought to determine if a relationship exists between these variables, spinal shrinkage incurred, and recovery from spinal shrinkage. Research does indicate a relationship between the rate and magnitude which compressive force is applied and the amount of spinal shrinkage incurred (Broberg, 1993; Haher et al., 1993; Nachemson, 1976; Reilly, 2010; Roaf, 1960; Sward et al., 1990; White & Panjabi, 1990). Therefore, it is assumed that the conditions exposing the body to greater GRF while running would result in greater spinal shrinkage. However, further research is necessary to determine if these relationships exist and what impact they have on recovery from spinal shrinkage.

The experimental protocol for this study required all running to occur on a motorized treadmill at an incline of 0° and constant speed. Studies have indicated that running surface and incline can influence the amount of GRF experienced by a runner (Cavanaugh, 1990; Novacheck, 1997). Therefore, the use of a treadmill may have affected the amount of GRF absorbed, spinal shrinkage incurred, and recovery observed. The results from the present study may not reflect what variation could occur due to different running surfaces and incline. No study currently exists assessing the impact of running surface and incline on spinal shrinkage and recovery from spinal shrinkage.

Summary

The aim of the present study was to assess the immediate effectiveness of four supine spinal unloading positions in recovering from spinal shrinkage incurred while running. Researchers sought to determine if a significant difference in recovery would occur between positions. Results from this study suggest that all supine spinal unloading positions are effective in providing a statistically significant recovery from spinal shrinkage incurred while running.

However, no statistically significant difference was observed in the amount of recovery reported between positions. Much of the current research has sought to determine the effects of various factors on spinal shrinkage. Future research should consider expanding their knowledge of the effects of these factors on the ability to recover from spinal shrinkage. Additionally, studies similar to the current study comparing multiple positions should consider using clinical populations such as individuals with low-back pain. Expanding the knowledge in this area would provide beneficial information for recreational runners, rehabilitation specialists, and coaches about a potential injury prevention technique that could be easily implemented in a variety of environments.

APPENDIX

CONSENT FORM

Informed Consent For:
Effectiveness of Spinal Unloading Positions in Recovering from
Spinal Shrinkage Incurred While Running

Principle Investigator

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Purpose and Benefits

Running exposes the body to a compressive force equal to 2 to 4 times your body weight each time your foot strikes the ground. As the compressive force is experienced, soft structures between each vertebrae called intervertebral discs act as shock absorbers. The height of each individual disc progressively reduces as this force is applied repetitively over time, resulting in changes to overall length of the spine known as spinal shrinkage. Although this occurs naturally as a part of daily life, it occurs more rapidly in activities such as running. The chronic application of this compressive force has been identified as a potential cause of low back pain and injury among runners. Spinal unloading is a technique that removes the compressive effects of gravity by lying down to allow the spine to lengthen. The effectiveness of several positions has been analyzed in separate studies; however no comparison has been made within one study. I am interested in assessing and comparing the immediate effectiveness of the four most commonly used positions. This study would be beneficial for recreational runners, coaches, and rehabilitation specialists of a potential injury prevention technique that is easily implemented in a variety of environments. This study will also fulfill academic requirements for my thesis in earning my Master's degree.

Procedures

To be eligible for participation in this study you must be a healthy male or female adult (18-30 yrs), and be a recreational runner (running at least 20 minutes, 1-3 times weekly). Runners reporting a history of musculoskeletal injury to the spine within one year prior to the study and/or currently experiencing pain within the spine or back will be excluded from this study. If you have any additional musculoskeletal, neurological, or disease limitations that would inhibit your ability to complete the study, you will not be eligible to participate. In order to participate you must be capable of performing a 15-minute run at a comfortable pace and lie on your back for the duration of 20-minutes. You must also be willing to expose the lower portion of your spine for the use of a diagnostic ultrasound to record measurements. For participation, you must wear comfortable athletic clothing and athletic shoes. If you decide to participate in this study, you must sign this form before the study begins. Even if you decide that you wish to participate in this study, you always have the choice to withdraw from the study at any time.

All data will be collected at the Eastern Washington University Riverpoint Campus (Spokane, WA) in the Health Sciences Building room 231. Health screening and consent forms will be collected during a familiarization day one week prior to the start of the study. At that time you will also be measured for height and weight, and asked your birthdate in addition to questions regarding your running history and injury history. You will then be lead through a modified running protocol to determine your treadmill speed for data collection days. For this study, repeated images will be taken using a diagnostic ultrasound to determine changes in intervertebral disc height. To ensure accuracy for the placement of the ultrasound device on data collection days, the investigator will need to touch and mark three locations on your skin: the fifth lumbar vertebra, midline of the spine, and placement for ultrasound device. A permanent ink pen will be used to mark these locations and will be reapplied over the course of the following 4 days as necessary. Once these locations have been marked, you will be led through one series of sitting height and ultrasound measurements.

Each data collection day you will begin by applying a chest strap heart rate monitor and wristwatch receiver. You will be randomly assigned 1 of 4 spinal unloading positions to be performed that day. I will perform an initial series of sitting height measurements and ultrasound images. Following these measurements, you will perform the randomly selected unloading position for 20 minutes. Upon the conclusion of the unloading period, I will conduct a second series of sitting height measurements and ultrasound images. You will then complete a running protocol for 20 minutes (5 minutes warm up and 15 minute run) on a treadmill at the speed determined on the familiarization day. Your heart rate will be recorded every 3 minutes to maintain intensity. Upon the completion of the run, I will perform a third series of sitting height measurements and ultrasound images. You will be asked to perform the assigned spinal unloading position again for another 20 minutes, followed by a final series of sitting height measurements and ultrasound measurements.

You participation in this study will last approximately 1 hour and 30 minutes on four separate testing days to complete all measurements, running protocols, and spinal unloading positions.

Risk, Stress or Discomfort

The risks for you are minimal. A diagnostic ultrasound will be used to record changes in intervertebral disc height. Since the ultrasound does not use radiation, it is not dangerous and completely painless. To complete the ultrasound measurements you must expose the lumbar region of your spine. Measurements will be recorded in an area away from other participants and research assistants to maintain your privacy and comfort. You will be asked to wear a heart rate monitor chest strap and watch during the running protocol. Minor irritation or skin redness may occur from the chest strap.

Other Information

Your participation in this study is strictly voluntary, and you may decide to withdraw at any time without penalty. Only the principle investigator and supervising faculty advisor will have access to your data. If you decide to no longer be part of the study, all of your data will be immediately destroyed. If you have any questions or wish to learn more about this study, please contact Jennifer Kumanchik at the phone number or email address listed at the beginning of this form.

Signature of Principal Investigator Date

The study described above has been explained to me and I voluntarily consent to participate in this research. I have had the opportunity to ask questions. I give permission to photograph, record, intercept, and/or divulge conversations in which I participate during this research. I understand that by signing this form I am not waiving my legal rights. I understand that I will receive a signed copy of this form.

Signature of Subject Date

If you have any concerns about your rights as a participant in this research or any complaints you wish to make, you may contact Ruth Galm, Human Protections Administrator (509-359-6567), or rgalm@ewu.edu.

APPENDIX

PHYSICAL ACTIVITIES READINESS-QUESTIONNAIRE

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of <u>any other reason</u> why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

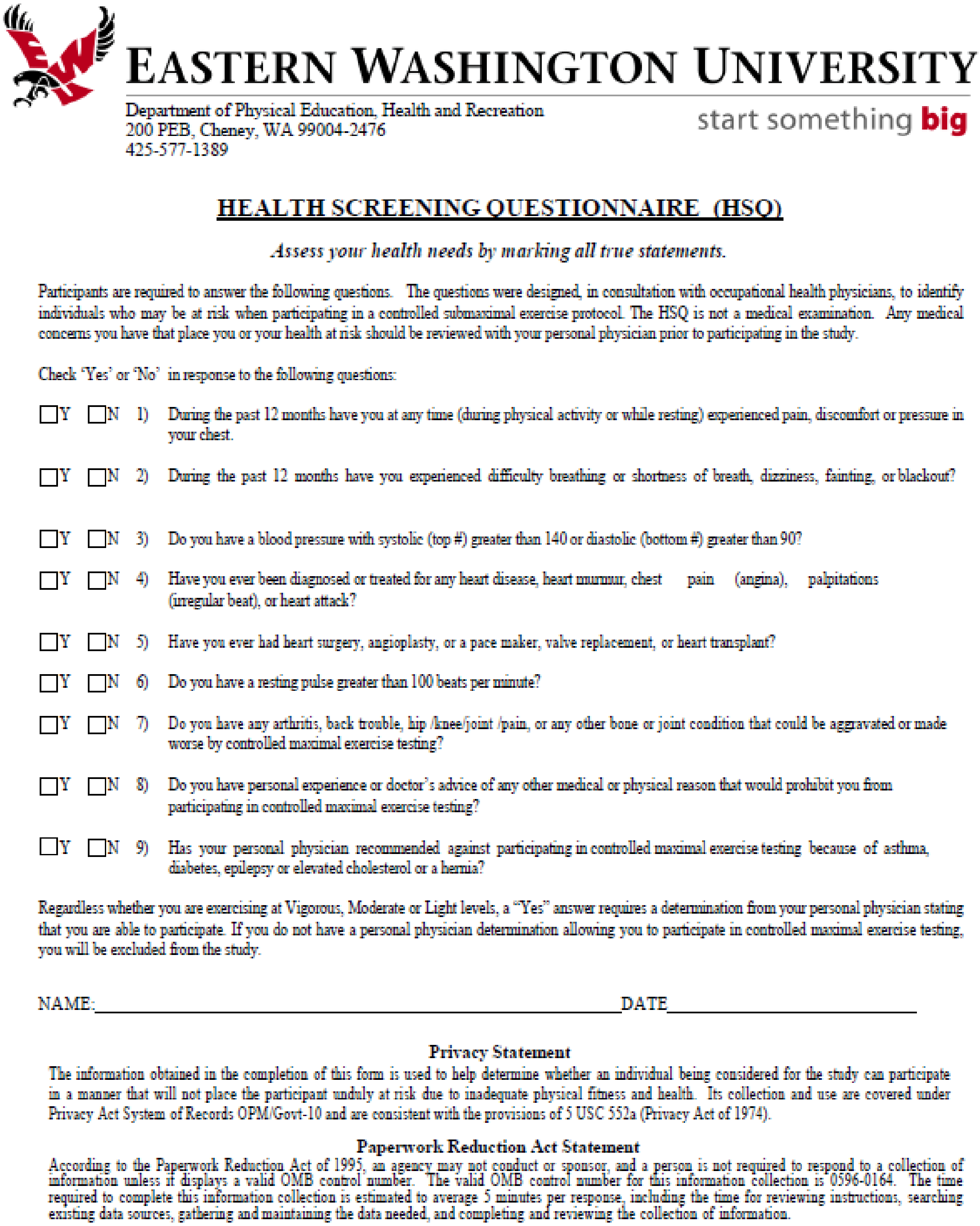
NAME ____

SIGNATURE ____ DATE ________________________________

SIGNATURE OF PARENT ____ WITNESS ________________________________
or GUARDIAN (for participants under the age of majority)

APPENDIX

HEALTH SCREENING QUESTIONNAIRE



EASTERN WASHINGTON UNIVERSITY

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425-577-1389

start something **big**

HEALTH SCREENING QUESTIONNAIRE (HSQ)

Assess your health needs by marking all true statements.

Participants are required to answer the following questions. The questions were designed, in consultation with occupational health physicians, to identify individuals who may be at risk when participating in a controlled submaximal exercise protocol. The HSQ is not a medical examination. Any medical concerns you have that place you or your health at risk should be reviewed with your personal physician prior to participating in the study.

Check 'Yes' or 'No' in response to the following questions:

☐Y ☐N 1) During the past 12 months have you at any time (during physical activity or while resting) experienced pain, discomfort or pressure in your chest.

☐Y ☐N 2) During the past 12 months have you experienced difficulty breathing or shortness of breath, dizziness, fainting, or blackout?

☐Y ☐N 3) Do you have a blood pressure with systolic (top #) greater than 140 or diastolic (bottom #) greater than 90?

☐Y ☐N 4) Have you ever been diagnosed or treated for any heart disease, heart murmur, chest pain (angina), palpitations (irregular beat), or heart attack?

☐Y ☐N 5) Have you ever had heart surgery, angioplasty, or a pace maker, valve replacement, or heart transplant?

☐Y ☐N 6) Do you have a resting pulse greater than 100 beats per minute?

☐Y ☐N 7) Do you have any arthritis, back trouble, hip /knee/joint /pain, or any other bone or joint condition that could be aggravated or made worse by controlled maximal exercise testing?

☐Y ☐N 8) Do you have personal experience or doctor's advice of any other medical or physical reason that would prohibit you from participating in controlled maximal exercise testing?

☐Y ☐N 9) Has your personal physician recommended against participating in controlled maximal exercise testing because of asthma, diabetes, epilepsy or elevated cholesterol or a hernia?

Regardless whether you are exercising at Vigorous, Moderate or Light levels, a "Yes" answer requires a determination from your personal physician stating that you are able to participate. If you do not have a personal physician determination allowing you to participate in controlled maximal exercise testing, you will be excluded from the study.

NAME:____DATE__________________________

Privacy Statement

The information obtained in the completion of this form is used to help determine whether an individual being considered for the study can participate in a manner that will not place the participant unduly at risk due to inadequate physical fitness and health. Its collection and use are covered under Privacy Act System of Records OPM/Govt-10 and are consistent with the provisions of 5 USC 552a (Privacy Act of 1974).

Paperwork Reduction Act Statement

According to the Paperwork Reduction Act of 1995, an agency may not conduct or sponsor, and a person is not required to respond to a collection of information unless if displays a valid OMB control number. The valid OMB control number for this information collection is 0596-0164. The time required to complete this information collection is estimated to average 5 minutes per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information.

References

Ahrens, S. (1994). The effect of age on intervertebral disc compression during running. *Journal of Orthopedic and Sports Physical Therapy, 20*(1), 17-21.

Beil, Andrew (1997). *Trail Guide to the Human Body*. Boulder, CO, Andrew Biel LMP.

Bogduk, N., & Twomey, L. (1997). *Clinical Anatomy of the Lumbar Spine and Sacrum.* New York, NY, Churchill Livingstone.

Bohu, Y., Julia, M., Bagate, C., Peyrin, J., Colonna, J., Thoreux, P., Pascal-Moussellard, H. (2009). Declining incidence of catastrophic spine injuries in French rugby. *The American Journal of Sports Medicine, 37*(2), 319-323.

Boocock, M., Reilly, T., Linge, K., & Troup, J. (1986). Fine measurement of stature for studying spinal loading. *Ergonomics,* 98-103.

Boocock, M., Garbutt, G., Reilly, T., Linge, K., & Troup J. (1988). The effects of gravity inversion on exercise-induced spinal loading. *Ergonomics, 31*, 1631-1637.

Boocock, M., Garbutt, G., Reilly, T., Linge, K., & Troup, J. (1989). Changes in stature following drop-jumping and post exercise gravity inversion. *Medicine and Science in Sports and Exercise, 22*, 385-390.

Broberg, K. (1993). Slow deformation of intervertebral discs. *Journal of Biomechanics, 26*(4-5), 501-512.

Carigg, S., & Hillemeyer, L. (1992). The effect of running induced intervertebral disc compression on thoracolumbar vertebral column mobility in young, healthy, males. *Journal of Orthopedic and Sports Physical Therapy, 16*(1), 19-24.

Cavanaugh, P. (1990). *Biomechanics of Distance Running.* Champaign, IL, Human Kinetics.

Chin, K. (2012). Ultrasound assisted/guided neuraxial block. *International Symposium on Ultrasound and Regional Anesthesia,* 1-12.

Dmitriadis, A., Papagelopoulos, P., Smith, F., Mavrogenis, A., Pope, M., Karantanas, A., Hadjipavlou, A., & Katonis, P. (2011). Intervertebral disc changes after 1 hour of running: A study on athletes. *Journal of International Medical Research, 39,* 569-579.

Dowzer, C., Reilly, T., & Cable, N. (1998). Effects of deep and shallow water running on spinal shrinkage. *British Journal of Sports Medicine, 32*, 44-48.

Floyd, R. (2009). *Manual of Structural Kinesiology.* Burr Ridge, IL, McGraw Hill.
Fowler, N., Lees, A., & Reilly, T. (1994). Spinal shrinkage in loaded and unloaded drop jumping. *Ergonomics, 37*(1), 133-139.

Fowler, N., Rodacki, A., & Rodacki, C. (2005). Spinal shrinkage and recovery in women with and without low back pain. *Archives of Physical Medicine and Rehabilitation, 86*, 505-511.

Garbutt, G., Boocock, M., Reilly, T., & Troup, J. (1989) The effect of running speed on spinal shrinkage. *Journal of Sports Science, 7*, 77.

Garbutt, G., Boocock, M., Reilly, T., & Troup, J., (1990) Running speed and spinal shrinkage in runners with and without low back pain. *Medicine and Science of Sport and Exercise, 22,* 769-772.

General physical activities defined by level of intensity. *Centers for Disease Control and Prevention.* Retrieved from: http://www.cdc.gov/nccdphp/dnpa/physical/pdf/PA_Intensity_table_2_1.pdf.

Gerke, D., Brismee, J., Sizer, P., Dedrick, G., & James, C. (2011). Changes in spine height measurements following sustained mid-range and end-range flexion of the lumbar spine. *Applied Ergonomics, 42*(2), 331-336.

Haher, T., O'Brien, M., Kauffman, C., & Liao, K. (1993). Biomechanics of the spine in sports. *Spine Problems in Athletes, 12*(3), 449-463.

Healey, E., Fowler, N., Burden, A., & McEwan, I. (2004). The influence of different unloading positions upon stature and recovery and paraspinal muscle activity. *Clinical Biomechanics,* 1-7.

Hirsch, C. (1955). The reaction of intervertebral discs to compression forces. *The Journal of Bone and Joint Surgery, 37*(6), 1188-1196.

Kadziolka, R., Asztely, M., Hanai, K., Hansson, T., & Nachemson, A. (1981). Ultrasonic measurement of the lumbar spinal canal. *The Journal of Bone and Joint Surgery, 63*(4), 504-507.

Kanlayanaphotporn, R., Trott, P., Williams, M., & Fulton, I. (2001). Contribution of soft tissue deformation below the sacrum to the measurement of total height loss in sitting. *Ergonomics, 44*(7), 685-695.

Kapandji, I. (1974). *The Physiology of Joints.* New York, NY, Churchill Livingstone.

Karvonen, J., & Vuorimaa, T. (1988). Heart rate and exercise intensity during sports activities. *Journal of Sports Medicine, 5*(5), 303-311.

Kingsley, M., D'Silva, L., Jennings, C., Humphries, B., Dalbo, V., & Scanlan, A. (2012). Moderate intensity running causes intervertebral disc compression in young adults. *Medicine and Science of Sports and Exercise, 44*(11), 2199-2204.

Kraemer, J., Kolditz, D., & Gowin, R. (1985). Water and electrolyte content of human intervertebral discs under variable load. *Spine, 10*(1), 69-71.

Leatt, P., Reilly, T., & Troup, J., (1986). Spinal loading during circuit weight-training and running. *British Journal of Sports Medicine, 20*, 119-124.

Ledsome, J., Lessoway, V., Susak, L., Gagnon, F., Gagnon, R., & Wing, P. (1996). Diurnal changes in lumbar intervertebral distance, measured using ultrasound. *Spine, 21*(14), 1671-1675.

Loizides, A., Peer, S., Plaikner, M., Spiss, V., Galiano, K., Obernauer, J., & Gruber, H. (2011). Ultrasound-guided injections in the lumbar spine. *Medical Ultrasonography, 13*(1), 54-58.

Magnussen, M., & Pope, M. (1996). Body height changes with hyperextension. *Clinical Biomechanics, 12*(2), 236-238.

Nachemson, A. (1976). *In vivo* measurements of intradiscal pressure. *The Journal of Bone and Joint Surgery, 46*(5), 1077-1091.

Naish, C., Mitchell, R., Innes, J., Halliwell, M., & McNally, D. (2003). Ultrasound imaging of the intervertebral disc. *Spine, 28*(2), 107-113.

Novacheck, T. (1997). The biomechanics of running. *Gait and Posture, 7,* 77-95.

Owens, C., Brismee, J., Pennell, P., Dedrick, G., Sizer, P., James, R. (2009). Changes in spinal height following sustained lumbar flexion and extension postures: A clinical measure of intervertebral disc hydration using stadiometry. *Journal of Manipulative and Physiological Therapeutics, 32*(5), 358-363.

Reilly, T., Grant, R., Linge, K., & Troup, J. (1988). Spinal shrinkage during treadmill running. *New Horizons in Human Movement, 3*, 412.

Reilly, T. (2010). *Ergonomics in Sport and Physical Activity.* Champaign, IL, Human Kinetics.

Roaf, R. (1960). A study of the mechanics of spinal injuries. *The Journal of Bone and Joint Surgery, 42*(4), 810-823.

Rodacki, C., Fowler, N., Rodacki, A., & Birch, K. (2003). Stature loss and recovery in pregnant women with and without low back pain. *Physical Medicine and Rehabilitation, 84*, 507-512.
Rodacki, C., Rodacki, A., Ugrinowitsch, C., Zielinski, D., & Budal da Costa, R. (2007). Spinal unloading after abdominal exercises. *Clinical Biomechanics, 23*, 8-14.

Roush, J., Schlicht, J., Flannagan, S. (2004). Changes in vertical column height, lumbar curves, and thoracic curves at half-time intervals during a 3-mile run. *Journal of Orthopedic and Sports Physical Therapy, 34*(1), 64-65.

Seay, J., Selbie, W., & Hamill, J. (2008). *In vivo* lumbo-sacral forces and moments during constant speed running at different stride lengths. *Journal of Sports Sciences, 26*(14), 1519-1529.

Shao, Z., Rompe, G., Schiltenwolf, M. (2002). Radiographic changes in the lumbar intervertebral discs and lumbar vertebrae with age. *Spine, 27*(3), 263-268.

State of the sport. (2014, July). *Running USA*. Retrieved from http://www.runningusa.org/state-of-sport-2013-part-III?returnTo=annual-reports.

Sward, L., Hellstrom, M., & Jacobsson, B. (1990). Back pain and radiologic changes in the thoraco-lumbar spine of athletes. *Spine, 15*, 124-129.

Taunton, J., Ryan, M., Clement, D., Mckenzie, D., Lloyd-Smith, D., & Zumbo, B., (2003). A prospective study of running injuries: the Vancouver Sun Run "In Training" clinics. *British Journal of Sports Medicine, 37,* 239-244.

Tyrrell, A., Reilly, T., & Troup J. (1985). Circadian variation in stature and spinal loading. *Spine, 10,* 161-164.

Van Deursen, L., Van Deursen, D., Snijders, C., & Wilke, H. (2005). Relationship between everyday activities and spinal shrinkage. *Clinical Biomechanics, 20*(5), 547-550.

Vehrs, P., George, J., Fellingham, G., Plowman, S., & Dustman-Allen, K. (2007). Submaximal treadmill exercise test to predict VO2 max in fit adults. *Measurement in Physical Education and Exercise, 11*(2), 61-72.

White, A., & Panjabi, M. (1990). *Clinical Biomechanics of the Spine.* Baltimore, MD: Lippincott Williams & Wilkins.

White, T., & Malone, T. (1990). Effects of running on intervertebral disc height. *Journal of Orthopedic and Sports Physical Therapy, 12*(4), 139-146.

Wilby, J., Linge, K., Reilly, T., & Troup, J. (2005). Spinal shrinkage in females: circadian variation and the effects of circuit training. *Ergonomics, 30*(1), 47-54.

Wilke, J., Neef, P., Caimi, M., Hoogland, T., & Claes, L. (1999). New *in vivo* measurements of pressure in the intervertebral disc in daily life. *Spine, 24*(8), 755-762.

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