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Sirsasana (Headstand) Technique Alters Head/Neck Loading: Considerations for Safety

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Sirsasana (Headstand) Technique Alters Head/Neck Loading: Considerations for Safety

by

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Thesis

Presented to the Faculty of the Graduate School

of the University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Kinesiology

The University of Texas at Austin

May 2012

This thesis is dedicated to my grandmothers, Sally and Leanna.

Acknowledgements

Many thanks to my support system: Chris, Jess, Mom, and Dad.

And thank you to Samira Kamran, Richard Head and Fahad Sharwani, the extra eyes, ears, and hands who made data collection happen.

Thanks to the super speedy R and stats help of Dr. Domingue and my husband Chris.

Thanks to my professors and mentors, Dr. Jensen, Dr. Abraham, and Dr. Emmer, for pairing guidance with inquiry.

And lastly, thanks to Erika Lima who successfully encouraged me to pursue a graduate degree. She said, "You have lots of icing, but no cake."

Thanks to everyone for the cake.

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Headstand, the *king* of all yoga poses, requires practitioners to support the full body with the forearms and crown of the head. A goal of novice and expert practitioners alike, sirsasana performance technique significantly modifies head and neck loads. This study examined the weight-bearing responsibility of the head and neck (separate from the arms) at moments of peak force during entry, stability, and exit of three typical performance methods. The three methods were: symmetrical extended leg (SE), symmetrical flexed leg (SF), and asymmetrical flexed leg (AF). Three groups of 15 participants each (2 males, 13 females) were formed, each group performing one technique. All 45 subjects (18-60 years of age) reported an active yoga practice including sirsasana with no record of cervical injury. After a 10 min warm up, participants performed three headstands. Kinematic and kinetic Vicon data were analyzed to locate peak forces acting on the head, loading rate of those forces, center of pressure, and neck angle at C3 in the frontal plane. Force plate data revealed flexed leg techniques produced the greatest forces during entry and nominal forces on exit. The SE condition produced lower forces on entry as well as slower loading rates during stability. In the frontal plane, neck angle about C3 tended towards neutral, or natural cervical lordosis, in SE and flexion in SF and AF during entry. COP showed no significant differences between groups; however, lateral movement at the apex of the head was markedly larger than movement in the sagittal plane for all techniques. Previous research has shown flexed loading, rapid loading and larger loads can increase potential damage to the cervical spine especially in women and aging individuals. As that population is heavily represented in yoga studios, the data support the conclusion that modifying headstand technique may reduce some of the mechanical risks of headstand.

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Chapter One: Introduction

Since its introduction into American culture just over a century ago, yoga has gained popularity as a modern method of obtaining states of meditation, wellness and physical fitness. Now a 6 billion dollar industry, this ancient mind-body practice has more than 15.8 million Americans regularly coming to their mats to reap the studied stress-relieving benefits of practice (YIAS, 2008). Practitioners pour into yoga studios to perform complex postures and conscious breathing exercises shown to collectively reduce stress, improve mood, bolster immunity, increase flexibility, improve sleep and aid in recovery processes (Curtis, 2011; Cohen, 2004; Bower, 2005; Gururaja, 2011; Hegde, 2011). However as the study of physiological aspects of yoga move forward in the scientific literature, the biomechanical aspects of what actually takes place on the mat are being ignored. Yoga practices often ask the body to move into uncommon positions. Inquiry into the structural impact of these potentially more risky positions is needed due to the repetitive nature of yoga practice, the lack of biomechanical research in this arena, and yoga's growing popularity across age groups.

Various pairings of spinal action (eg: flexion, extension) and body position (eg: kneeling, supine) make up the asana, or posture, portion of a yoga practice. Inversions, often encouraged due to their level of challenge and benefits, present a particularly atypical deviation from our standing, seated or supine behavior. Improved focus, reduced heart rate, calming effects, encouragement of venous return, movement of lymph, improvement of immune function, flush of toxins and strength gains in the trunk, upper body and respiratory diaphragm are all touted as benefits accrued in yoga inversion practices. Headstand, known as the "king of all postures" is held up in yogic literature as a cure all for issues of circulation, the common cold, back pain and depression (Iyengar, 1964). Modern research concludes that yoga asana (including headstand) does, in fact, combat the symptoms of depression (Woolery, Myers, Sternlieb, & Zeltzer, 2004) and observes marked shifts in circulation during the asana as well as shortly after the performance of it (Rao, 1968). In 1926, Kuvalayananda, an Indian scientist found increased blood pressure readings in 11 healthy headstanding adults that slowly dropped, although not to initial values, during the static stability phase in which the subject maintained the posture (Kuvalayananda, 1926). Forty-two years later, Rao Shankar conducted a battery of physiological tests on young males during headstanding. In addition to validating the 1926 work, he found that heart rate was lower in headstanding than standing, inspiratory capacity was greatest upside down and that the oxygen utilization in headstand was greater than standing or supine (Shankar, 1962; Shankar, 1968).

When offered the in-class opportunity to perform headstand, the average western practitioner will be told to refrain from the pose if they are experiencing hypertension, glaucoma, detached-retina, pregnancy, cervical dysfunction, menstruation, heart conditions or other serious medical concerns. Just like the list of benefits, there is some validity to these precautions. Headstanding is well-known to increase intra-ocular pressure (IOP) and central retinal arterial pressure, potentially resulting in short and long term vision loss in individuals with pre-existing ocular pathology (Sanborn, 1987). This increase in IOP is greater when passively inverted than when upright and exercising at target heart rate. Due to this information and observation of increased systemic blood pressure as well as central retinal arterial pressure, Klatz, a leading investigator in the realm of inversion therapy, concluded that individuals with heart conditions, family history of stroke, hietal hernia, and hypertension should avoid full inversion (Klatz, 1983). Pregnant and menstruating women are encouraged to do partial inversions wherein the back rests on the floor and the legs are up in the air. This is considered safer for the woman as her abdominal wall may be compromised during pregnancy and she may enter the pose only to find the muscular support she was expecting has changed or is no longer there. Additionally, the baby may shift to a less desirable location. From the yogic perspective, a menstruating woman should not interfere with the natural downward flow of her monthly cycle by fully inverting. The current literature does not address either issue.

While "cervical dysfunction" appears to be a rational precaution when approaching headstand, it is a non-specific blanket warning, also absent from the literature. During headstand the practitioner loads his or her body weight onto the head and arms, reversing the relationship of gravity on the spine commonly experienced in upright standing and sitting. The headstand method of loading requires the smaller vertebrae of the cervical spine to bear larger loads. Although the discs and vertebrae are intended to aid in redistribution of force, their ability to do so depends on their size, shape, and condition (Einhorn, 1992; Adams, 2000). Intervertebral mobility, especially in the cervical spine, exhibits decreases with increasing age (Gower, 1969). Decreased mobility, larger loads, repeated loads and asymmetrical loads all result in disc degeneration (Walter, 2011; Lotz, 2000; Matsumoto, 2010). Considering that nearly 60% of the current United States yoga population currently falls within at risk categories in terms of age (35-70) for disc degeneration, investigation into forces acting on the head is warranted (YIAS, 2008; Matsumoto, 2010).

A biomechanical examination of the common yogic practice of supported headstand (*sirsasana*), is a first step of detailing the mechanics of the pose in an effort to increase studied benefits and reduce risks. In the posture, the forearms are on the floor, hands clasped around the back of the skull, and the crown of the head is also in contact with the floor. While individual differences result in challenges with classification, typical entry (often modified by preferred yogic lineage) occurs in one of three ways: legs symmetrical and straight, legs symmetrical and bent, and legs asymmetrical bent or straight. Entry and exit techniques are generally paired and stability, or the static performance of the pose, is without noticeable difference across all techniques. This study is an initiation of the biomechanical examination of *Sirsasana* with a description and comparison of these loading conditions and factors that contribute to increased or asymmetrical loads during the three phases of headstanding -- entry, stability, and exit.

Magnitude of ground reaction force acting on the crown of the head, and subsequently the cervical region, as separated out from forces acting on the arms, is the main interest in this inquiry. Previous research findings have shown that larger loads, repeated loads and asymmetrical loads all result in increased disc degeneration in the cervical region (Walter, 2011; Lotz, 2000; Matsumoto, 2010). Inquiry into the cervical conditions of African wood-bearers, individuals practiced at loading the head, found increased degeneration and pain among male and female wood bearers bearing increased loads (Jager, 1997; Josaab, 1994). The literature reporting cadaver cervical spine failure loads reports a range of 300N to 17kN (Cusick 2001) with men consistently having 600N more loading capacity (Pintar, 1998). This investigation will determine baseline estimates of average and maximum forces acting on the head and neck during entry, stability, and exit. Forces will be further partitioned by entry/exit technique across the three time periods to determine if technique plays a role in the magnitude of cervical loading.

Within each technique force loading rate will be assessed to describe the rate of change of the load during a single performance of the posture. Loading rate modulates type of injury due to the altered mechanics of loading. At lower rates, ligaments and discs can absorb more force but at higher rates they cannot absorb as much. Therefore, higher loading rates rely on the vertebrae to bear the load (Cusick, 2001). Due to the natural degeneration of the viscoelastic properties of the spine, the vertebrae itself absorbs more of the force with increased age (Pintar, 1998).

Mechanics of force distribution and tolerance differ at various cervical relationships. A neck angle about C3 as described by its vector relationships between C7 and the left ear, will provide a non-invasive description of compression. States of direct compression (natural lordotic cervical curve compression) and compression-extension offer a cervical failure rate that is four times greater than that of cervical-flexion (Carter, 2002). Compression of a straightened cervical curve or one in deeper flexion results in the greatest number of neck injuries resulting in neurological deficits (McElhaney, 1993). Static stance of all subjects will be processed as an initial or comparative neck measurement against which inversion neck angles can be compared. Neck angle will be examined at times of peak force and peak loading rate within each time period and compared across the three methods to determine relative compression behaviors at points of interest.

The trajectory of the origin of the ground reaction force vector reported as the center of pressure (COP) will be calculated in terms of distance travelled over time. This distance will be further partitioned into lateral and frontal movement and compared across time and between techniques to determine balancing accommodations that may alter direction of force. This value will be an initial determination of both the restraint, or stillness of the head as well as the apex of the force vector. Restraint of the head has been found to generate greater forces and an increase in the probability of fractures (Yoganandan, 1986). Laterally located apexes are more likely to produce lateral fractures and nerve root avulsion (McElhaney, 1993).

Upon determination of load magnitude, loading rate, cervical alignment and force vector movements during each of the three entry methods, dependent measures will be compared to questionnaire inquiries including issues of experience, frequency, weight, age, and gender. Potential correlations may reveal further areas of study or contributors to force modulation.

Headstanding loading patterns are repeated events in a yoga practitioner's lifestyle. The discs and spinal segments of these individuals may be undergoing asymmetrical and symmetrical loads at areas of marked risk and reduced mobility potentially resulting in cell death and spinal column damage. Considering that 6.9% of adults in the United States participate in yoga regularly, a look into headstand procedures and their resultant forces and lines of symmetry at peak forces is a first step in examining the structural efficacy of these practices.

Chapter Two: Background: An Eastern Practice in a Western World

Yoga, a mind-body discipline that originated in India over 5,000 years ago, found its way to the western world in the late 1800's. Traveling via gurus, curious celebrities, and soul-searching wanderers, the practice of yoga in the United States slowly became more accessible and mainstream as it grew in popularity over the last century. These days, according to a 2008 study, 15.8 million Americans, or 6.9% of the populace, regularly incorporate the practice of yoga into their lives (YIAS, 2008). What was originally a fringe pastime has become a $6 billion dollar enterprise complete with magazines, advertising campaigns, yoga gear, national presenters, teacher training schools and, of course, yoga studios and classes.

Although yoga was originally intended to have a strong spiritual component, the relatively new yoga in the west focuses heavily on the physical aspects of the practice with varying levels of introduction to *pranayama* (breathing techniques) and to *dhyana* (meditation) (Satchidananda, 2008). The term "yoga" actually means "to yoke" or to create union between the mind and the body and the types of yoga and methods of creating this union are numerous and vary greatly. Most yoga classes within western culture contain similar elements including a sequence of postures, breath awareness, and a rest period called *savasana*. The postures performed are derived from pairings between one of five body positions (standing, prone, supine, kneeling/seating postures, and inversion) and one of five spinal movements (flexion, extension, rotation, lateral flexion/extension and axial extension). Many of these pairings result in moving the body through a range of motion unlike regular daily activities or other forms of exercise. As the practitioners move into a posture dynamically and then maintain a static position, they are urged to move only within the limits of their capability as indicated by the breath. In short, if the breathing is challenged, the posture is too intense.

The Science of Yoga: Modern Research

Regardless of the cultural deconstruction and alteration of ancient yoga practices as they spread from their homeland, individuals continue to report reaping the noted benefits. In the late 1970's, the Yoga Biomedical Trust of London was the first non-Indian affiliation to compile information related to yoga studies and self-reported relief from symptoms of various health issues among practitioners. They noted that individuals with back pain, arthritis, anxiety, heart disease, duodenal ulcers, cancer and alcoholism reported a 90-100% relief of major symptoms as a result of a disciplined yoga practice. They reported a 68-89% benefit in more than ten other common ailments as well. These findings as well as the dozens of other yoga-related studies that have surfaced in step with the increasing popularity of yoga in recent years aim to provide scientific support to generic claims coming from the practicing public.

Yoga as complementary medicine for various psychiatric disorders is one popular arena of study. Both Visceglia (2011) and Duraiswamy (2007) found marked improvements in the management of schizophrenic symptoms as compared to traditional therapies alone. Subjects that performed a yoga routine including inversions such as headstand observed improvements in quality of life, social functioning and a decrease in psychotic symptoms and disorganized thinking. Japanese scientist Gururaja (2011) found a decrease in salivary amylase, indicating reductions in trait and state anxiety among both young and old yoga practitioners as compared to non-yogis. Woolery (2004), who found similar reductions of anxiety during a 5-week yoga intervention study, also found decreases in depression state, both self-reported and as measured by blood cortisol levels. Initial physiological reductions in anxiety and depression symptoms continued to improve with long-term practice (Yoshihara, 2011).

Yoga has also been cited as a beneficial modality in the reduction of symptoms related to various autoimmune disorders, diseases, hormonal shifts, recovery processes (such as chemotherapy) and other stress-induced ailments (Curtis, 2011; Hedge, 2011; Joshi, 2011; Singh, 2011). Patients recovering from cancer found improved sleep, energy levels, mood, and reductions of cancer-related symptomology as compared to patients not receiving a yoga intervention (Bower, 2005; Cohen, 2004). Higher infant birth weights and reduced pregnancy complications resulted from a yoga intervention on 68 women as compared to the 53 pregnant expectant mothers in the control group that only engaged in walking (Narendran, 2005). Individuals with dementia exhibited fewer problem behaviors and reduced depression as compared to matched counterparts (Fan 2011). The mechanism behind many of these relatively recent findings relates to the known connections between mental state and the hypothalamic-pituitary-adrenal axis. Regulation of cortisol and reduction of norepinephrine and epinephrine results in a reduction of stress responses and an increase in numerous study outcomes (eg: quality of life, mood, anxiety-reduction) (Arora, 2008).

Research into the physiology and functional benefit of yoga has taken prominence while research on the anatomy and mechanics of yoga postures has lagged behind. Inquiries into the efficacy of yoga programs as treatments for lower back and neck pain aside, the actual components, the combinations of body positions and spinal movements remain largely unstudied (Tekur, 2008; Williams, 2009; Yogitha, 2010). There are no scientific standards for these movements in terms of performance or sequence, but rather various schools of thought. In the vast majority of yoga studies, the actual practice of yoga is somewhat of a black box with various uncontrolled (and often un-recorded) combinations of movement, breathing and meditation. In order to refine desired outcomes of a yoga practice and to further understand the acute impacts on the body, individual sequences and postures need to be examined more thoroughly to reduce musculoskeletal injuries. A survey of 110 practitioners of a flow-based practice that includes headstand reported that 62% incurred an injury that affected them for longer than four weeks (Mikkonen, 2008). In a survey of 1,336 yoga practitioners worldwide, 674 cited the neck and cervical spine as one of the most likely potential sites of injury from yoga practice. Headstand, shoulderstand, and plow pose were noted as the postures most likely to cause an injury to the neck (Fishman, 2009). In short, practitioners are aware that headstand may compromise musculoskeletal neck health; however, modifiers of that risk are currently unknown.

Inversions: Structural and Functional Effects

The practice of yoga postures combines five body positions with five spinal movements. Study of the dynamic and static effects of each of these combinations is possible. The inverted state is the most commonly studied aspect of those combinations at present due to its uniqueness and potential risks. A full inversion aligns the legs and hips over the heart and above the head; therefore, it presents the most novel and least common experience for the body. Inversions are viewed as peak postures in yoga classes due to their level of challenge and purported benefits including: improved focus, reduced heart rate, calming effect, reduction in depression, encouragement of venous return, movement of lymph, improvement of immune function, flushing of toxins and strength gains in the trunk, upper body and respiratory diaphragm.

Benefits of inversions have been studied with a mix of outcomes. Thanks to the 1980 film *American Gigolo*, which depicts Richard Gear hanging upside down in Dr. Robert Martin's 1965 invention, the Gravity Boot, popularity of inversion exercises, therapy and equipment increased dramatically during the 1980's (*Time,* 1983). Early work on inversion therapy found marked reprieves from pain generated by nerve-root impingements in the lumbar spine after short periods of inversion therapy (Sheffield, 1964). Later inquiry related to pain reduction included findings of reduced EMG activity in the lumbar musculature after 70 seconds of passive inversion (Nosse, 1978) and increased intervertebral dimensions after 10 minute durations (Kane, 1985).

Inverting creates a number of pressure changes in the body. Suspended forms of inversion have been found to increase blood pressure, central retinal arterial pressures, and intraocular pressure (Klatz, 1983). Klatz and company took measurements of 20 healthy individuals pre-inversion, 45 s into the inversion, and at 3 min. They found that central retinal arterial pressure increased from 45/26 to 105/62 mmHg and systemic blood pressure increased from 119/74 to 157/93 mmHg. Intraocular pressure increased from 19 to 35 mmHg. In a follow-up study the same year, Klatz compared the values at inversion to values of upright exercise at target heart rate and found that the inversion generated much greater values of all pressure outcomes. Klatz concluded that inversion might prove dangerous in individuals with "glaucoma, hypertension, uncompensated congestive heart failure, carotid artery stenosis, hiatal hernia or spinal instability, persons receiving anticoagulants or aspirin therapy, those above age 55 or those with a family history of cerebrovascular accidents." (Klatz, 1983; p. 539)

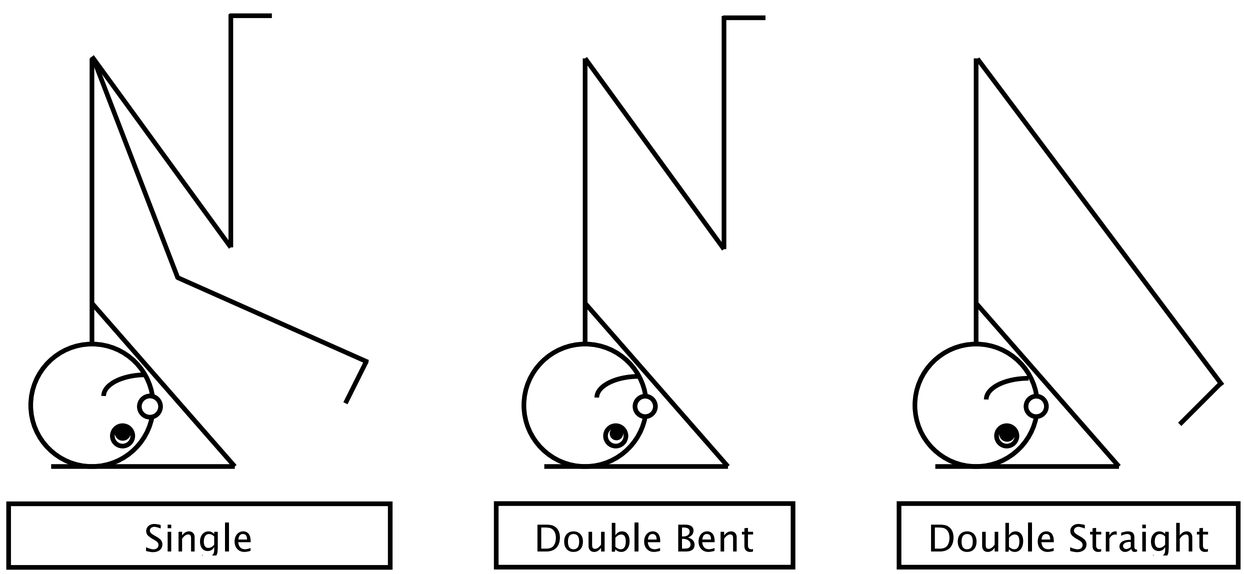
In 1985, Goldman and his team (Goldman, 1985) hypothesized that previously recorded increases in blood pressure and heart rate were due to subject anxiety surrounding inversion. To combat this confound, he took 20 healthy men and had them perform 80-150 oscillations on an inversion table over the course of 15 min. He measured systolic and diastolic blood pressures, intraocular pressure (IOP), pulse rate and central retinal arterial pressure (CRP) prior to inversion and again at 5, 10, and 15 min of inversion. Goldman found that systolic and diastolic BP along with pulse rate all decreased with no initial increase noted at the 5 min collection. Systolic and diastolic CRP as well as IOP all increased by nearly double at the 5 min recording due to hydrostatic pressure and then minimally decreased during the remaining period of the inversion but not to pre-inversion levels. Goldman concluded that inversion can have a calming effect and exhibit a reduction in blood pressure and heart rate due to the aid in venous return due to gravity; however, the findings regarding increased pressure in the fluid behind the eye and the arteries that provide blood flow to the retina concurred with Klatz' findings.

Further study of suspended inversion, comparing various passive inversion systems, also found a decrease in heart rate during inversion (Ballantyne, 1986). Theoretically, inversion generates increased blood pressure in the upper body and activates baroreceptors that slow heart rate and reduce blood pressure. Findings otherwise often cited methodological differences and subject anxiety as reasons that the research results were not conclusive with theoretical models.

Headstand: the "King of All Asanas"

Sirsasana, or yoga headstand, is known as the king of all asanas and is viewed through the yogic lens as a cure all for issues of circulation, common cold, back pain and depression (Iyengar, 1964). *Sirsasana* is taught in many modern day yoga classes. Some yoga practices, such as Sivananda and Ashtanga, include headstand in every practice sequence, and other practices choose to incorporate it less frequently. Unlike the task used in previous studies on inversion, *sirsasana* completed actively with the head on the floor, the hands cradling the back of the head and the forearms pressing down to support the weight of the body. The visible differences between techniques are in the behavior of the legs. There are three commonly taught methods of entering and exiting this posture: symmetrical extended legs (SE), symmetrical flexed legs (SF), and asymmetrical flexed legs (AF). (See Figure 1) Technique is dependent on instructor preference or background, yoga lineage, and physical abilities of the practitioner. Not all headstanders can perform the pose using all of these techniques. Headstand practitioners generally practice one of the methods with regularity.

Figure 1



The first recorded headstand study was conducted by Kuvalayananda in 1926. He studied 11 healthy young adults with normal blood pressure (BP) results and recorded changes before, during and after headstand. He found that BP increased upon entry into the pose but decreased every minute thereafter although not to levels associated with upright posture. Between 1961 and 1968, Rao Shankar, a prolific Indian scientist, conducted a series of descriptive studies on the headstand posture. In his first study, he recorded the metabolic costs of 6 healthy young males in states of lying down, standing, and headstanding. He found that the cost of oxygen utilization during headstand exceeded the supine position by 68.6% and the standing position by 48%. The second study examined cardiovascular factors measured across the same body positions (held for five min each) within the same population previously studied. Heart rate went from 84 beats per minute (bpm) during standing to 69 bpm in the headstanding posture and dropped to 63-67 bpm during a supine position. This reduction of heart rate after headstand is independent of active or passive inversion (Manjunath, 2003). Brachial BP measure increased in the headstanding posture as did finger blood flow. Conversely, toe blood flow decreased in headstand. Dr. Rao completed his exploration of headstand with another study of similar methodology that examined respiratory response to headstand. As compared to headstanding, he found that vital capacity was greater in an upright position and that inspiratory capacity was greater upside down.

Hypertension concerns aside, the other contra-indications mainly come from investigations and case studies related to pressure build up behind the eye. Just as the passive inversion procedures generated increases in intraocular pressure and central retinal arterial pressure, research in the area of active headstand has verified these findings and indicates that they may cause short or long-term vision damage (Sanborn, 1987). Unlike heart rate or BP, which were seen to potentially decrease over time, IOP exhibits a mean increase of 15.1 mmHg upon entry and increases to 15.8 mmHg after five min of static practice bringing the total mean IOP to approximately 30mmHg (Baskaran, 2006). This increase represents a healthy eye. This pressure has been shown to increase to 50 mmHG in an individual's eye that already exhibited disease: congenital glaucoma (De Barros, 2008). This individual, who had been practicing the posture for five years despite ocular pathology, suffered from progressive glaucomatous neuropathy and loss of visual acuity due to inverting (De Barros, 2008). Progressive glaucomatous neuropathy has also been found in less severe cases of glaucoma patients who were also regularly performing headstand (Gallardo, 2006).

Based upon the research conducted related to inversion and, more specifically, to headstand, individuals displaying conditions that are negatively affected by increased BP and IOP can make educated choices about the option to invert within the context of a yoga class provided they are informed. The hydrostatic effects of the cerebrospinal fluid and the activation of baroreceptors in the neck serve to explain the mechanisms related to increased pressure behind the eyes, and decreased heart rate and BP over time as the practitioner remains in the pose (Robin, 2002). However, unlike the research on passive inversion, biomechanical principles and descriptions of headstand do not exist in the literature despite the fact that they are commonly practiced maneuvers that involve supporting one's body weight through the smaller vertebral bodies that are less practiced at doing so. Many of the studies listed in the overall benefits section of this review included "inversions" in their methodology, indicating, along with the supporting literature on passive inversion, that benefits are currently believed to exist and warrant continuation of this practice (Woolery, 2004). Research into the structural aspects of this posture are needed to ensure its safety for various populations.

Mechanical Risks of Headstand

The kinesiology of headstand and the spine's ability to safely sustain the load of an individual in an inverted position is unpublished. A basic understanding of the spine's behavior is available from the analysis of other loading tasks and provides scaffolding upon which an argument may be built to conduct such research. Basic descriptions of loading and unloading forces, positional information at maximum forces, and potential shearing stressors across techniques are suggested outcomes for a starting point.

The mobility that the spine enjoys in yoga is allowed by the fibrous discs. Each disc consists of an outer ring called an annulus and an inner portion called the nucleus. When force travels through the spine, the discs are compressed between the bones. The liquid-quality of the discs serves to absorb shock and redistribute the load. The liquid can do this because it is non-compressible as it is contained by the fibrocartilage of the annulus. However, various pathologies and injuries can break down the disc or cause disruptions in the structure and; consequently, the function. These pathologies come from a number of factors, one of the simplest of which is age. In old age, the discs may go from 90% water content to below 70% (Hirsch, 1954; Gower, 1969).

In a neutral position, the cervical spine has a natural lordotic curve and the main force upon the discs and bones is one of compression. The discs and their adjacent vertebral segments have articulating surfaces that are designed to absorb and distribute force under compressive loads. Loads transfer anteriorly through the vertebral body and disc and posteriorly through the facets and lateral masses (Pintar, 1995). There are bending moments and shear forces that accompany various movements and create increased mechanical challenges to the spine. Sitting, even in an upright position, is more taxing on the spinal components than standing (Kaminska, 2010). During headstand, the spine moves from a forward bend similar to sitting into a place of natural standing curvature and then returns to a forward bend. The exact relationships depend on performance method. While compression is the main force in the extended position, theoretically bending and shearing forces also occur during entry and exit not to mention that theses force are occurring at greater magnitudes in the upper spine, which is loading the weight.

The cervical spine is designed to carry the weight of the skull and its contents. The individual composition of bones affects their weight-bearing capacity as does their shape (Einhorn, 1992). Vertebral bones are made primarily of spongy or trabecular bone which is more porous in nature and already more prone to fracture (Einhorn, 1992). Repeated loading of the bone into the plastic region of its stress-strain curve may result in fracture (Einhorn, 1992). In this way, loading of additional weight that pushes one or more vertebrae into the plastic region may go unnoticed at each load but cumulate over time to a negative effect. African wood bearers who are practiced at carrying large loads on the head provide a closer look into cervical loading. Of 35 male wood bearers, 88.6% exhibited cervical degeneration as compared to only 22.9% of their matched non-wood bearing peers (Jager, 1997). Elimination of the natural lordosis was also seen in the cervical spines of wood bearers (Josaab, 1994) and female bearers carrying large loads (50-60kg) had more prolapsed discs, herniations and listhesis than those with moderate loads (30-35kg) (Echarri, 2001; Echarri, 2005). Larger loads also resulted in reports of greater neck pain (Echarri, 2005). Due to the repetitive nature of headstand over long periods of time, much like wood bearing, load magnitude is a concern.

Maximum load to failure of components of the cervical spine as tested on cadavers currently ranges from 300N to 17kN (Cusick, 2001). Male cadavers are consistently 600 N stronger in terms of force to failure rate (Pintar, 1998). This gives an estimate of force tolerance levels in the neck; however, it is not a perfect value as it does not account for the activity of the surrounding muscle tissue in a live specimen. When the spine is restrained in order to simulate the stabilizing properties of neck musculature, larger fractures and forces were generated (Yoganandan, 1986). This indicates that muscular stability or restraint may not increase neck failure loads. Age, gender, disease, endocrine function, congenital factors and arthritis all affect tolerance values (Cusick, 2001).

Spinal alignment patterns during loading alter loading mechanics and resulting injuries (Cusick, 2001). Loading beyond tolerance levels in axial compression (a straightened cervical spine) and flexion-compression are more likely to result in damage to the vertebral bodies including burst fractures, whereas over-loading in extension-compression is more likely to damage the anterior longitudinal ligament of the vertebral arches (Cusick, 2001). The most vulnerable configuration of spinal alignment is in a state without a natural curve (also called pre-flexion or axial loading). In this alignment, spinal injury due to buckling failure is common as the viscoelastic areas of the spine are unable to aid in weight distribution so the vertebral bodies bear the load (Liu, 1989). This is the stiffest configuration of the spine and can tolerate larger loads with increased risk such as tackling with the head down in football or heading a soccer ball (Burstein, 1982).

Ligaments and discs can absorb more force during lower loading velocities but at higher rates the ratio of stiffness between the tissues and the bones changes (Cusick, 2001). Larger rates put a greater responsibility on the vertebrae. This increase is less noticeable in older spines that may have a decrease in intervertebral disc size and are therefore already relying on the vertebrae to absorb more force (Pintar, 1998). Again, loading rate modifies type of ensuing injury. Rapid loading reduces the ability of soft tissues to absorb the load; therefore, potential injuries from sudden forces are more likely to have neurological involvement due to buckling of the vertebrae themselves.

Damage to the shape, minor damage to the bone structure of a vertebra, results in structural changes to the neighboring discs thereby challenging future mobility. Adams found that the loading of the discs under damaged vertebral endplates shifted pressure from a deflated nucleus to the annulus of the disc. In many cases, the annulus itself began to bulge under moderate repetitive loads. Fifty to 70 year-old discs suffered the most (Adams, 2000). Over 18% of the current yoga population is over the age of 55 with another 40% falling within the 35-55 year range (YIAS, 2008).

When examining loads on the discs themselves, the mechanics of each disc, just like each vertebra, exhibit individual values for stress tolerated. Determinants of these values include type of loading and loading history, as well as location of the disc (McNally, 1992). Although the disc is built for and intended to carry loads, many factors limit its ability to do so. Shape of the disc affects its capacity to bear repeat loads (Yates, 2010). Age results in a decreased range of motion at many spinal segments, especially cervical segments. That decreased range of motion is positively correlated with disc degeneration (Simpson, 2008; Okada, 2009). Degeneration of the discs in one area of the spine is often related to degeneration in other areas (Matsumoto, 1976).

Another indicator of the nucleus' ability to tolerate axial loads is the number of cells in the cellular matrix. Increased numbers of nucleus cells resulted in greater pressures tolerated (Cao, 2011). However, the magnitude and duration of spinal loading have been correlated to intervertebral cell death and damage in a mouse model thereby reducing the ability of the spine to bear loads (Lotz, 2000). The more asymmetrical, or complex, the loading pattern the more likely cell damage is to occur (Walter, 2011).

Headstanding loading patterns are repeated events in a yoga practitioners lifestyle. Many practitioners are within the boundaries of the aging populations as indicated by the research on spinal strength and function. This indicates that the discs and spinal segments of these individuals may be undergoing asymmetrical and symmetrical loads at areas of marked risk and reduced mobility potentially resulting in cell death and spinal column damage. Considering that practitioners use three methodologies to perform headstand, a look into those procedures and their resultant forces and lines of symmetry at peak forces is a first step in examining the structural efficacy of headstanding practices.

Chapter Three: Methods

Recruitment

Forty-five subjects were recruited from the local yoga community, via online message boards related to yoga in Austin, Texas, as well as from flyer (see Appendix B) placement at studios and yoga venues. After acquisition of initial subjects, the snowball technique was used to recruit additional potential participants who exhibited an interest and met study criterion. Participants were screened prior to arrival and subsequently recruited based upon their age (18 years old and up), their self-report of freedom from chronic neck injury, and their ability to perform a supported headstand for five breath cycles with minimal assistance. Individuals performing headstand outside of the context of yoga practice were not considered. Criterion set insured that each individual was a low-risk semi-regular practitioner of the activity.

Consent, Questionnaire, and Group Descriptions

Upon arrival for the single 60-min study visit to the Developmental Motor Control Laboratory located in 546B Belmont Hall at the University of Texas at Austin, subjects signed a consent form and were given a copy for their records (Appendix C). Then they filled out a questionnaire indicating their age, gender, years of yoga and headstanding experience, and frequency of their yoga and headstanding practice. At this time, they also indicated their preferred method of entry into the posture: symmetrical extended legs, symmetrical bent legs, or asymmetrical legs. Three groups, based upon these three methods of entry, were formed totaling 45 subjects. It should be noted that individuals performing headstand tend to do so in the same method each time and often cannot achieve the pose if the method of entry is altered. In order to generate the comparisons across groups, means were closely matched in the areas of age, gender, and yoga experience level. This was achieved via oversampling followed by the elimination of five subjects prior to data analysis. No significant difference in terms of age, weight, and years of experience were found. All groups contained 13 females and 2 males.

The three groups represent the three most commonly used techniques within the context of led yoga classes. The symmetrical extended group (SE) entered and exited the pose with legs together and straight (SE, n=15 (13 female, 2 male), 60.0 ± 6.8 kg, 36.9 ± 8.8 years of age, 8.1 ± 4.5 years of yoga experience). The symmetrical flexed group (SF) entered the pose with symmetrical thighs and flexed knees (SF, n=15 (13 female, 2 male), 61.8 ± 12.5 kg, 37.9 ± 11.1 years of age, 8.8 ± 5.7 years of yoga experience). The asymmetrical flexed group (AF entered the pose one leg at a time with the legs in varying levels of flexion (AF, n=15 (13 female, 2 male), 67.1 kg ± 17.6 kg, 32.3 ± 9.2 years of age, 6.8 ± 3.6 years of yoga experience). Although the majority of SF and AF subjects entered and exited the pose in the same way, a handful exhibited more or less control on the way out of the posture resulting in a classification challenge. All subjects were classified based upon entry technique.

Protocol, Data Collection and Equipment

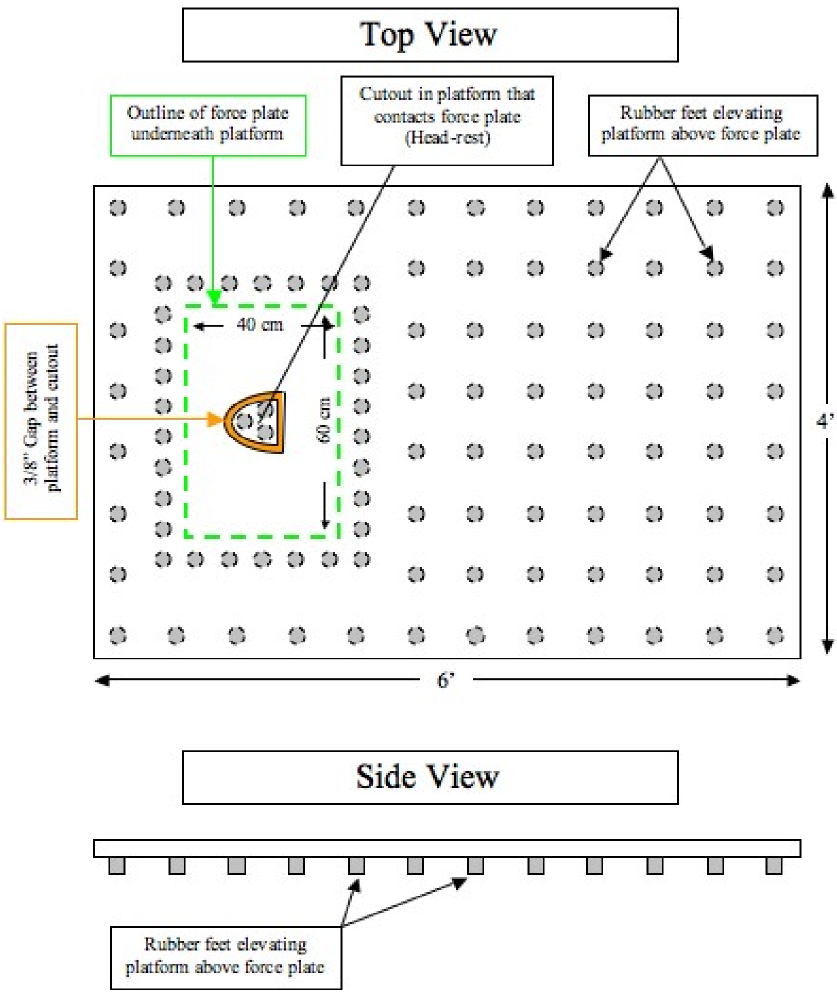
Upon completion of paperwork and necessary explanations, all subjects completed a 10-min warm up on their own yoga mat regardless of previous activities. They were instructed to engage in self-guided yoga-related movements in silence with the knowledge that they would be performing *Sirsasana* (headstand) after the allotted time period. In this way, yoga practitioners who practice headstand spontaneously would be warmed up and those who understand how to prepare certain areas of the body for inversion had the time to do so. Some yoga traditions offer headstand and inversions at the beginning of class to ensure the practitioner is not fatigued, and others offer it later to ensure the practitioner is strong enough to maintain it. None of the subjects were challenged by the freedom of the 10-min warm-up. Most of the subjects naturally did a flow-based warm-up consisting of sun salutations, standing postures, and hip and hamstring openers although this was not recorded in any way.

After the warm-up, 18 reflective markers for the 10-camera motion capture system (Vicon) were attached to the subject and one marker was placed on the force plate as a point of reference. Subjects wore tight-fitting non-reflective clothing, wore their hair up and off the face and neck, and removed earrings. Pre-prepared markers were secured with double-stick adhesive to the following 18 locations: right and left earlobes, chin, center of the forehead, right and left lateral epicondyles of the humerus, right and left acromion processes, right and left greater trochanters, right and left lateral condyles of the femur, base of second toe on the right and left foot, C3, C7, T9, and L5 (see Appendix D). None of these markers interfered with headstand or standing performance.

With the markers affixed, subjects took one stationary trial standing on the force plate (Bertec). They were asked to stand quietly in a yogic stance: Tadasana or Mountain Pose. A short trial was collected to record the baseline ground reaction force acting through the legs for later comparison to the ground reaction force acting on the head. This trial also served as a way to observe natural standing head position, cervical length, and overall body weight and height. This trial was processed immediately to ensure data capturing systems were functioning properly so as not to discover errors during the more intensive trials. Following this procedure, a 4x6 foot platform covered with a thick yoga mat was placed over the 40x60 centimeter force plate. (See Figure 2) The experimenter indicated to the subject to place the crown of the head inside the red semi-circle on the mat and then placed the 19th marker 10 inches away from the back of the subject's clasped hands. This marker aided in describing the subject's base during data analysis as markers were not placed on the back of the head or hands as a safety precaution. Three headstand trials were captured with the practitioner placing their head on the location of the platform indicated by a semi-circle. The subject was instructed to begin when ready and to maintain the pose for five self-paced breaths prior to exiting it. A requisite two-min rest period was enforced between trials to minimize. the effects of fatigue and anxiety and to safeguard against risk. During each trial, spotting was provided regardless of need and no didactic instruction was given aside from the reassurance that the subject could come down at any time if needed. Sampling rate of 120 Hz was used for x, y, z coordinate data. The analog signal from the force plate was sampled at 1200 Hz. The force data were down-sampled from 1200 Hz to 120 Hz to match coordinate data with the analog signal.

Figure 2

Headstand Platform



It should be noted that the section of the mat where the practitioner placed his or her head was in full contact with the force plate; however, the section under the arms was floating, held up by rubber “feet” surrounding the plate. The practitioner was not aware of this fact and could not feel the difference between the free-floating area touching the plate and the area not touching the plate because the gap the wood panel was too small to notice beneath the thickness of the mat. To them, it was a flat, stable surface. The platform rested a total, including the board itself, 1.5 in. above the floor and was larger than a typical yoga practice space. With this platform method, only the ground reaction force acting on the head was recorded. To monitor that this piece of equipment was appropriately located, the experimenter observed the visual representation of real-time forces on the computer monitor as the subject put his or her forearms on the mat and then his or her head. The experimenter saw no visible forces when the arms were placed and then saw a nominal force when the head was initially situated. Additionally, practice runs, whereupon a weight was placed on the board but not on the circle itself were collected monthly. During these tests, no force was reported, indicating that the board was still intact and functioning properly.

After the third trial, markers were removed and the subject performed a required five-min yoga-related cool-down on their own personal mat. During this time, the headstand trials were processed and capture assured.

Dependent Variables

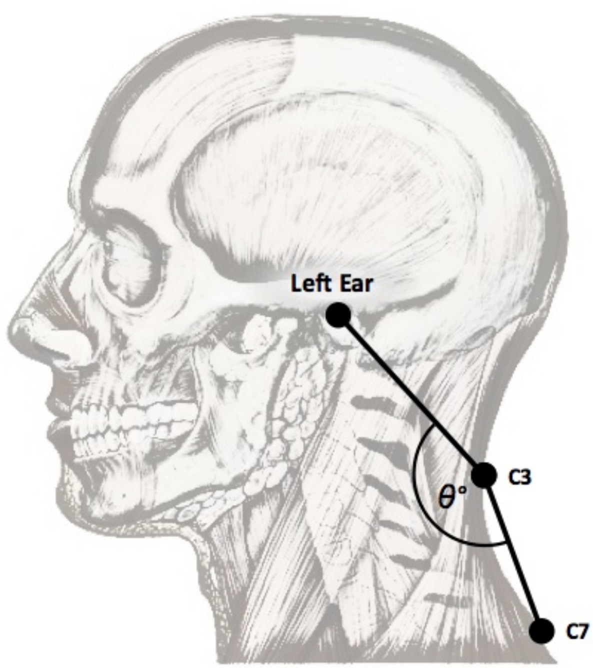
Force was the primary dependent measure in this study. In an effort to discern if one of the three entry/exit methods of supported headstand generated greater loading patterns on the head, maximum load and average load (entry, stability and exit) between the three methods were calculated. All force outcomes were calculated and compared as raw values in addition to being normalized to the subject's total standing force.

Loading rate described the rate of change of the force. Differences between samples (previously down-sampled to 120 Hz) were then calculated as absolute values and divided by time. Average and maximum loading rates were reported for each time period and compared between the three methods.

The ground reaction force acting on the head is a resultant vector reported from the force plate. The origin of that force vector, known the center of pressure (COP), was another examined measure in this study. In order to describe and compare the behavior of the central axis of the force acting on the head and neck, the excursion, or total distance travelled by the COP in all directions was calculated as velocity per second to determine movement taking place at the foundation as the posture was performed. These differences in COP were compared across time periods (entry, stability and exit) between the three methods. COP was also broken into component parts of COPx and COPy in an effort to examine difference between lateral and frontal movement on the crown of the head.

Neck angle, a measure of the head in relationship to the trunk that described the angle about the third cervical vertebrae was calculated to examine flexion and extension of the neck during the task. Using the values of the left ear (LE), C3 and C7 from the lateral perspective, the dot product of the vector from C3 to C7 and the vector from C3 to LE were calculated. (see Figure 2) To compare and describe the the differences in neck flexion/extension, angle at maximum load and maximum loading rate were calculated per time period and compared across the three time periods and between the three methods.

Figure 2



Design and Statistical and Data Analysis

This was an experimental project comparing three headstand techniques. These techniques are commonly taught by teachers and/or performed by students in yoga classes. In this study, individuals performed only one variation of entry/exit into supported headstand. Each subject performed three trials. The first trial was considered a warm-up trial and the second two were analyzed on all measures previously described and then averaged together to boost power and reduce variability.

The statistical assessment was carried out with 3x3 repeated-measures ANOVAs for each dependent variable with time period as the within subjects component and method as the between subjects component. Following the ANOVA, post hoc procedures were calculated to discern notable pairwise comparisons. Levene's test was used to test for homogeneity of variance. Mauchly's test was used to test for violations of the sphericity assumption. Significance was reported for *p* values less than .05. Lastly, a multilevel linear model was fitted to determine contributing factors to average force.

The kinematic data were analyzed to determine toe off, toe down, and head position during points of interest. When the average vertical velocity of the toe marker over 100 ms was consistently at or greater than 10 mm/sec, toe off was marked. When that velocity dropped below 10 mm/sec, stability was marked as beginning and then marked again as ending when the velocity shifted to -10 mm/sec. Toe down was marked when velocity was greater than -10 mm/sec. Times associated with toe off, toe down and stability were double-checked with visual inspection. Toe off to the beginning of stability marked entry the entry phase. For single leg practitioners, toe off was based upon the second foot that left the ground and toe down was based upon the first foot that landed.

Gaps in Vicon camera system data because of momentarily hidden or untracked markers were filled via linear interpolation for gaps of up to 0.2 s. Larger gaps were not filled but rather eliminated from the analysis. This only affected the outcome measures of neck angle and cervical length. In the case of COP, gaps could not be filled via linear interpolation as the measure was non-linear. Instead, COP was considered stationary during periods of zero data as the practitioner's head was actually lifted off of the mat/plate during those times as confirmed by a simultaneous absence of force. In this way, when it returned to the plate, a deviation from center was not recorded. Analysis of the force data did not require interpolation or fill.

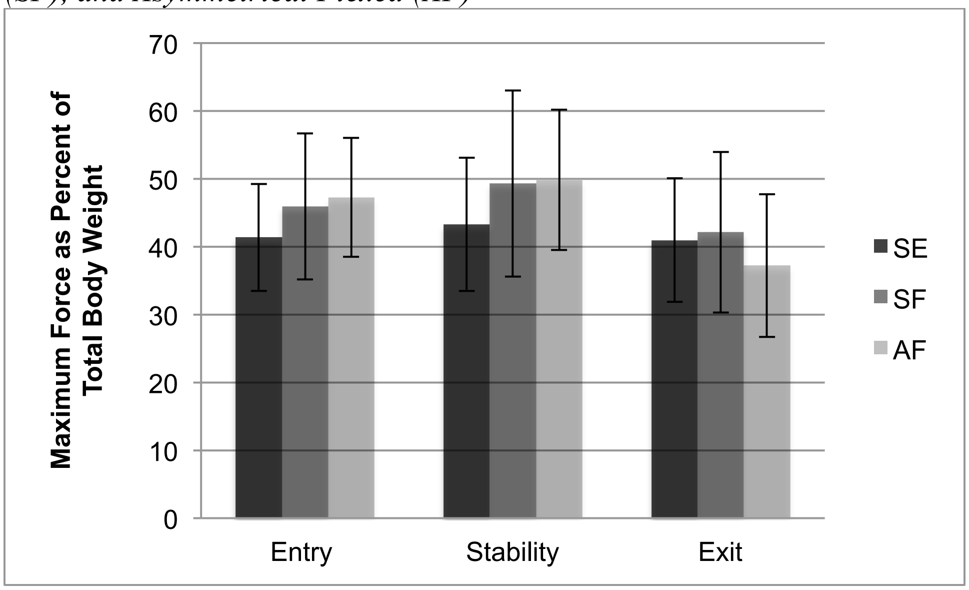
Chapter Four: Results

Force

This analysis reviewed the loads applied through the head during three time periods in the headstand – the entry, stability, and exit. The analysis revealed significant differences in the maximum force experienced across the three phases of the action and a significant difference for the interaction effect between time and method. Maximum forces acting on the crown of the head expressed as a percent of individual body weight differed across time periods, $F(2, 84) = 25.55$, $p < .000$. (See Figure 3) The interaction between time period and method was also significant, $F(4, 84) = 5.18$, $p = 001$. Pairwise comparisons further showed significant differences were present between all three time phases ($p<.01$). Although pairwise comparisons between methods were non-significant, effect sizes (Cohen's d) comparing the difference between one method and another over pooled between-subjects variance displayed moderate effects. During entry, the difference between SE and AF or SF was moderate (Cohen's d; .52 and .39 respectively) while the difference between SF and AF was of only low effect size (.12). Stability showed similar effect sizes. In relationship to SE, the values were .51 for AF and .47 for SF with the effect between AF and SF again being much smaller at .04. However, exit effects were small to non-existent. The effects between SE and the other two methods, AF and SF, were .29 and -.09 respectively. The largest exit effect size difference between methods was the one between SF and AF (Cohen's d, .38).

Figure 3

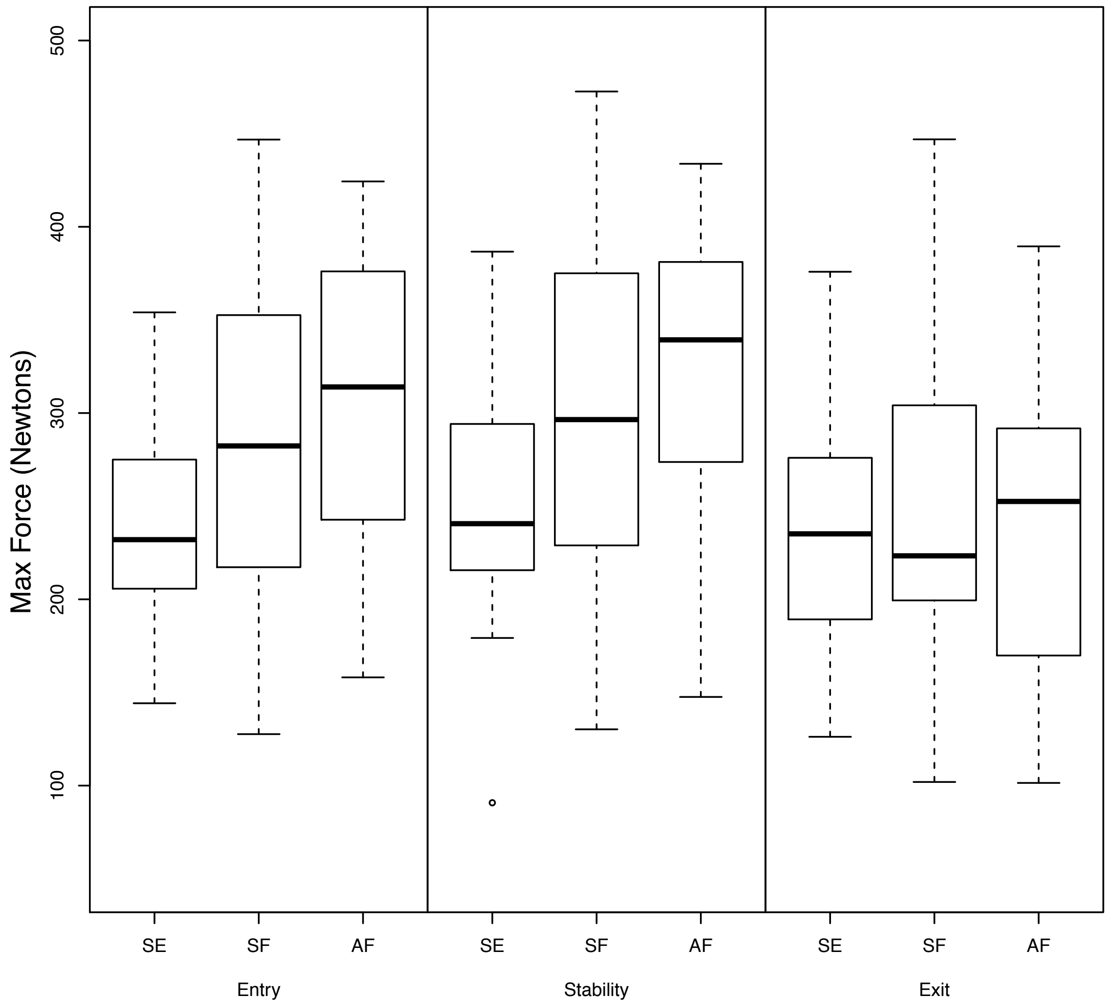
Maximum Forces as a Percentage of Individual Weight Acting on the Head During Each Time Period as Modified by Method: Symmetrical Extended (SE), Symmetrical Flexed (SF), and Asymmetrical Flexed (AF)



Maximum loads during entry and stability were above 300N on average for the AF group. The SF group exhibited midrange means in terms of maximum forces; however, it was the most variable of the techniques. SF subjects exhibited the highest and the lowest values on an individual basis. The trend in entry and stability does not hold for exit as AF and SF values drop while SE remains stable. (See Figure 4)

Figure 4

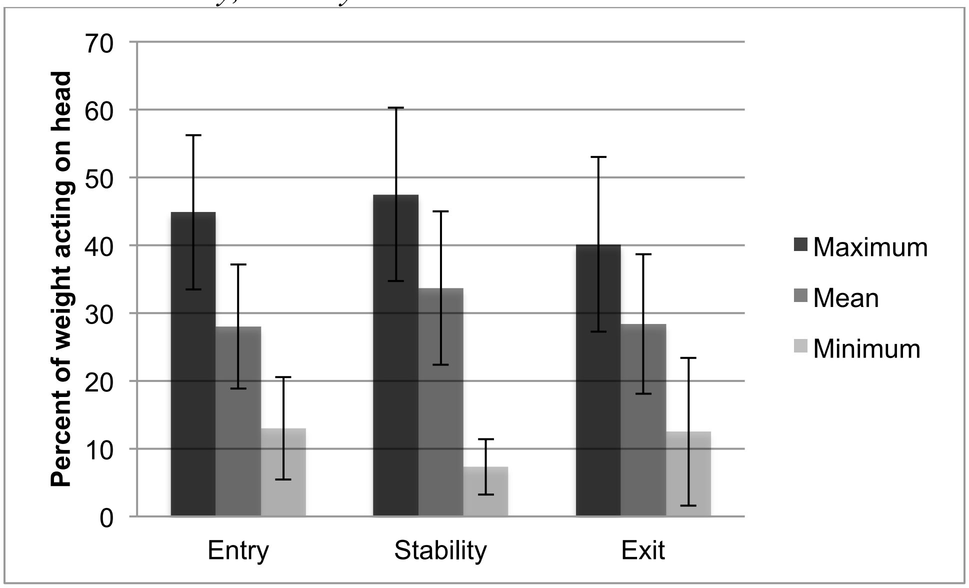
Maximum Forces Acting on the Head During Each Time Period associated with Method: Symmetrical Extended (SE), Symmetrical Flexed (SF), and Asymmetrical Flexed (AF)



Average force as a percent of individual body weight was significant across time periods, $F(2, 84) = 22.24$, p= .000, but not between methods $F(2, 42) = .25$, p= .78. Differences were found between time periods of entry and stability (p<.01) as well as between stability and exit (p<.01). Across all subjects, average load was 28.00% upon entry, 33.68% during stability, and 28.39% during exit. (See Figure 5)

Figure 5

Minimum, Average, and Maximum Forces Acting on the Head During Each Phase of Headstand: Entry, Stability and Exit

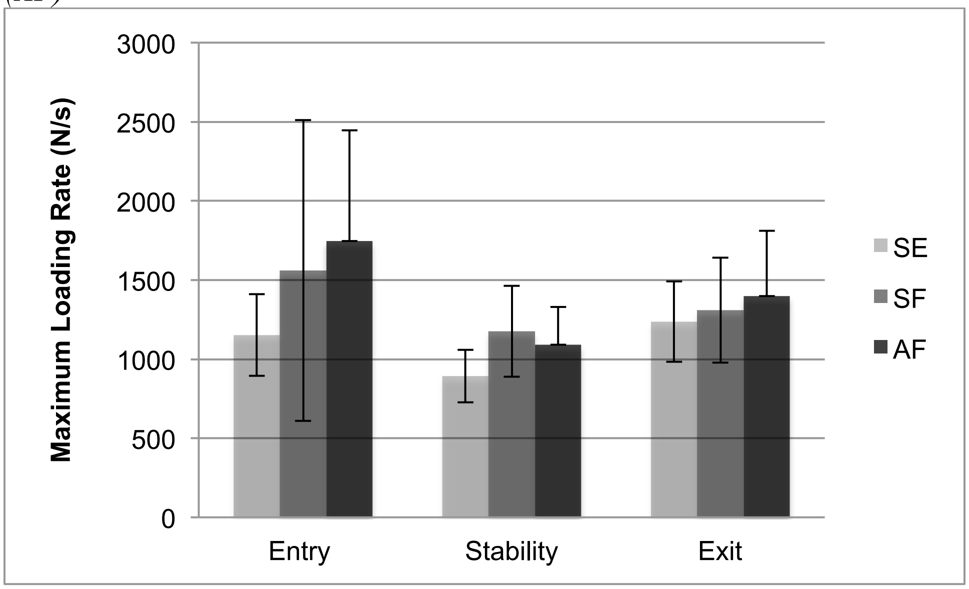


Loading Rate

The rate of change of the load acting on the head is described the loading rate. Maximum loading rate was significant across time periods, $F(1.51, 84) = 12.785$, p= .000 but interaction with method was not significant $F(3.03, 42) = 1.22$, p= .311. Maximum loading rate did differ significantly between methods, $F(2, 42) = 4.32$, p= .02 and one-way ANOVAs per time period with post hoc Bonferroni procedures revealed an approaching significant difference between SE and AF during entry (p = .074). Post hoc analysis also revealed a significant difference between SE and AF (p < .01) during stability while the difference between SE and SF approached significance (p = .078). No differences were found upon exit. (See Figure 6)

Figure 6

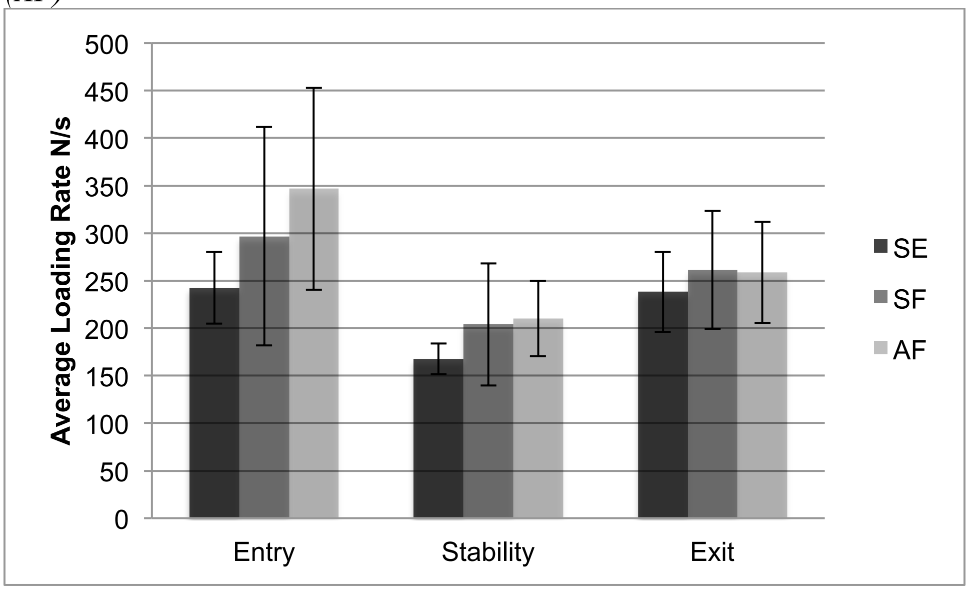
Absolute Maximum Force Rate of Change During Each Time Period as Modified by Method: Symmetrical Extended (SE), Symmetrical Flexed (SF), and Asymmetrical Flexed (AF)



Average loading rate behaved similarly to maximums with the exception of an interaction effect. Average loading rate was significant across time periods, $F(1.44, 84) = 50.72$, p= .000 and interaction with method was significant in this case $F(2.88, 84) = 3.20$, p= .031. Average loading rate did differ significantly between methods, $F(2, 42) = 4.32$, p= .02. Post hoc Bonferroni procedures revealed a significant difference between SE and AF during entry (p = .011). SE and AF also differed during stability (p = .039) with a difference between SE and SF approaching significance (p = .097). Again, no differences were found upon exit in terms of method. (See Figure 7)

Figure 7

Absolute Average Force Rate of Change During Each Time Period as Modified by Method: Symmetrical Extended (SE), Symmetrical Flexed (SF), and Asymmetrical Flexed (AF)



The results of the multilevel regression revealed a relationship between force and time during entry significant at the $\alpha = 0.01$ level. Each additional second of time taken to enter into headstand resulted in a reduction of 4% in average force acting on the neck and head regardless of method.

Neck Angle

Neck angle described the relationship of the head to the trunk about C3 in terms of flexion and extension. Neck angle calculation at baseline, or standing position, revealed an average between 140-141 degrees across all groups. Angles greater than baseline were in the direction of neck extension and angles smaller than baseline were in the direction of flexion. Neck flexion, especially in the SF condition, was notably more common during headstand than extension as compared to baseline. (See Table 1) Points of interest included neck angle at the time of maximum force and at the time of maximum loading rate. Neck angle at time of max force was not significant across time, between methods or as an interaction. Similarly, neck angle at time of maximum loading rate was not significant across time or between methods; however, interaction of time period and method of neck angle at time of maximum loading rate approached significance $F(2.53, 84) = 2.59$, $p = .072$. Further examination of effect sizes revealed moderate effects between methods during entry at time of max force and time of max loading rate. (Table 2) During entry, moderate effects were observed between SE and SF, p= .66 and SE and AF, p= .57 at the time of maximum force. Both SF and AF moved to a place of flexion at this time with neck angles decreasing to 123.26 and 125.69 degrees respectively. SF neck angle was 110.46 degrees at maximum loading rate during entry. Moderate effects sizes indicate that the magnitude of flexion found in SF subjects was not as large in AF or SE entry methods.

Table 1

Neck Angles at Baseline, Time of Maximum Force, and Maximum Loading Rate

		Entry		Stability		Exit	
	Baseline	Max Force	Max LR	Max Force	Max LR	Max Force	Max LR
SE	140.21	141.47	133.98	135.11	135.13	134.34	127.02
SF	140.18	123.26	110.46	130.96	131.26	129.51	134.77
AF	141.94	125.69	132.04	134.02	136.18	132.54	130.72

Table 2

Effect Sizes of Neck Angle Differences Between Method of Entry at Time of Maximum Force and Maximum Loading Rate

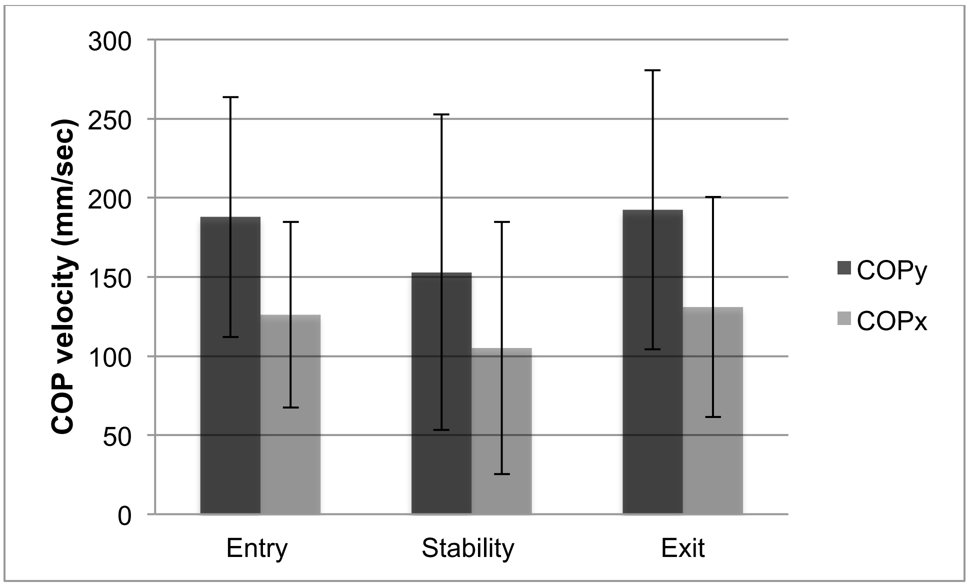
	Entry		Stability		Exit	
	Max Force	Max LR	Max Force	Max LR	Max Force	Max LR
SE:SF	0.66	0.64	0.27	0.26	0.23	-0.42
SE:AF	0.57	0.05	0.07	-0.07	0.09	-0.20
AF:SF	0.09	0.59	0.20	0.33	0.15	-0.22

Center of Pressure

Average COP excursion per second showed a main effect across time $F(2, 84) = 11.67$, $p < .01$. Differences were significant between entry and stability ($p< .01$) and stability and exit ($p< .01$). Movement at the base of support increased during entry and exit for all methods. To get a clearer picture of the direction of movement of these excursions, COP was divided into its x and y components. The y component described side-to-side movement and the x component described front-to-back movement. Both measures showed a main effect for time, $F(2, 84) = 12.74$, $p < .01$ for COPx and $F(2, 84) = 12.75$, $p < .01$ for COPy. Pairwise comparisons of both values were significant between entry and stability ($p< .01$) and stability and exit ($p< .01$). Further analysis revealed a significant difference between lateral (x) and frontal (y) movement during entry $F(1, 42) = 235.85$, $p < .01$, stability $F(1, 42) = 185.70$, $p < .01$, and exit $F(1, 42) = 207.19$, $p < .01$. None of these differences showed a main effect for method or an interaction. All practitioners produced more lateral movement at the crown of the head while navigating the balance between arms and head. (See Figure 8)

Figure 8

Lateral (y) and Frontal (x) Movement of Center of Pressure During Each Phase of Headstand



Questionnaire

Results of subject questionnaire revealed no correlation between maximum force upon entry and factors of weight, height, age, and neck angle. Yoga experience, $r(43) = .11$, $p = .47$, and headstand experience, $r(43) = .18$, $p = .23$, both revealed non-significant small positive correlations with max force during entry as did male gender $r(43) = .26$, $p = .08$. Average neck angle during entry was positively correlated with neck angle at a static stance, $r(43) = .44$, $p < .01$, and non-significantly with age, $r(43) = .21$, $p = .17$. Average loading rate of force during entry exhibited a moderate positive correlation with weight, $r(43) = .56$, $p < .01$, as well as smaller correlations with male gender $r(43) = .33$, $p = .03$, method $r(43) = .31$, $p = .04$, and height, $r(43) = .30$, $p = .05$.

Chapter Five: Discussion

Supported headstand (sirsasana) is a reoccurring practice in a yoga class and the number of yoga classes and practitioners is on the rise. This study took a first look at the load bearing responsibility and mechanical behavior of the head and neck as a base of support for yogic headstanding. It was determined that the average yogi loads the head with 30-50% of his or her body weight while performing this asana (posture) and that entry/exit technique is one contributor to modifying the load and subsequent neck alignment.

Entering headstand requires strength, flexibility, and an override of natural righting reflexes. Entrance technique depends largely on an individual's combination of these assets as well as his or her anatomical proportions. Individuals entering the posture with legs extended and together exhibited the lowest maximum and average forces during entry as well as the narrowest window of variation. During entry more than three-quarters of SE subjects stayed below 300N of vertical loading, a value indicated as the lowest load to cervical failure in the accumulated literature (Cusick, 2001). In contrast, more than one-half of the AF subjects experienced loads above the threshold. Entering with symmetrical but flexed legs trended towards mean AF values with a larger variation across the scores indicating that SE produced the lowest values outside of individual differences in the SF category.

Performance of the headstand causes a loading of the head and neck, but repeated loading as well, due to intrinsic bouncing and weight shifts between the arms and head. The speed at which the head was loaded was slowest during the SE entry technique. The SE trend towards lower entrance forces and longer times to entry showed that moving more slowly into the posture resulted in a decrease in average forces. Subjects performing the AF entry loaded the head more rapidly than the other two methods. Entering the pose with one leg at a time can be done slowly but more often than not the practitioner has to use momentum to approach the pose due to physical proportions or strength challenges.

Bending the knees into the chest and slowly lifting them simultaneously (SF) falls in between the other techniques in terms of load and rate of loading on entry. However, SF alignment of the neck during key times, peak force and peak loading rate during entry, moves into a position of flexion or axial compressive loading. Although increased load at any cervical alignment engenders a certain amount of risk, loading during flexion reduces load absorption by the viscoelastic areas of the cervical region including the ligaments and intervertebral discs. Cervical injuries under these circumstances are more likely to result in neurological damage than neutral or natural lordotic loading. SE practitioners were able to maintain this lordotic cervical curve during entry.

Highest loads and lowest loads were observed as subjects held the static posture for five breaths. SF and AF values trended towards larger maximum forces than SE with over half of those in the first two groups still exceeding 300N at maximum load. Considering that technique differences were not evident during static holding of the posture we hypothesize that lower loads and loading rates found in the SE category during this phase may be related to developed upper body strength and control. In short, these practitioners may have been more accustomed to intense upper body activation and controlled loading and have continued to utilize it during the headstand itself.

During stability, changes in center of pressure and neck angle were indistinguishable across techniques. All subjects did not have to move as much to balance a static load as opposed to a dynamic load; therefore, movement patterns at the crown of the head were noticeably smaller than during entry or exit. Neck angles across all techniques at maximum forces and loading rates exhibited very small amounts of flexion as compared to baseline non-inverted measures.

Loading rate and loads upon exit closely resemble those upon entry. Symmetrical extended practitioner loading rate and loads upon exit closely resemble those upon entry, again, probably due to more controlled movements. Loads upon exit for SF and AF techniques dropped down toward SE levels reducing force differences between the techniques. This drop in force and loading rate as compared to entry is likely due to a swift exit. While a few of the participants exited in a manner different than the manner in which they entered, the defining feature of the exit appears to speed rather than style. For example, practitioners in the SF and AF categories often exited the pose suddenly by pushing off with the arms and moving the legs back to the ground with a quick controlled fall. In this way, weight was lifted off of the head prior to landing.

The controlled fall exit strategy may explain the reduction of flexion in the neck on exit that was seen during SE entry. Interestingly, SE exit exhibited the largest amount of flexion at maximum loading rate during exit. SE practitioners may benefit from exiting via controlled fall to reduce this flexion, especially if they are fatigued and unable to control the exit well while still weight-bearing on the head.

Movement at the base of support increased during exit in conjunction with the return of dynamic loading. Lateral movement was greater than sagittal movement in all time periods as the practitioner worked to balance his or her body side-to-side.

Technique did not explain all the differences in dependent measures. Further investigation revealed that height, weight, gender and pre-existing neck condition may correlate to loading rate, load and neck alignment. The angle of the neck during entry was related to the neck angle when the individual was simply standing. Weight and height were positively associated with increased average loading rates, and increased maximum forces but were not factors in increased maximum forces when force was calculated as a percent of total body weight. A small to moderate relationship was found between maximum forces, loading rates and gender. Men tended to have higher loading rates and maximum forces; however, this observation was largely explained by their increased weight. Although age plays a role in cervical condition in the non-yoga population, it did not modify any aspect of headstand performance. Participating subjects ranged in yoga and headstanding experience from 6 months to 20 years and that experience was not a predictor of any outcomes.

Independent of technique, 30% of body weight is supported by the head during supported yoga headstanding. Additionally, the maximum load carried by the head during headstand approaches 50% percent of total load. By modifying entry technique, practitioners may be able to reduce this load and sudden changes in the load, thereby reducing the risks of sudden loading of the vertebral bodies of the cervical spine. Entering the posture with straight legs together may reduce load on the head and the rate of change of that load during entry and stability. Conversely, exiting the pose quickly with a push of the arms and a controlled one-legged fall appears to reduce cervical spine involvement upon exit.

Due to the variable nature of human bodies and headstand performance, further study is needed to determine the contribution of factors such as upper body proportions, age, and experience to understand the overall picture of cervical loading in headstand.

Appendix A: IRB Proposal

I. **Magnitude and angle of load during various entries into Headstand (Sirsasana)**

II. **Investigators:** Rachel E. Hector, Jody L. Jensen, Ph.D.

III. **Research Questions, or Goals of the Project**

A. **Question: How does headstand entry/exit, across three variations of the same style of headstand, affect overall safety and performance?**

i. **Percent increase, as compared to body weight, in max load passing through the head during all three phases (entry, stability, exit) will be greatest for single leg technique followed by double bent leg and lastly by double straight leg. (The three variations are depicted in Figure 1)**

1. **The dependant measure in question for this hypothesis is the force experienced through the head and neck. In terms of sustaining this activity, the method of entry/exit that exhibits the least change of force would be ideal.**

ii. **Change in the angle that defines the relationship between the head and the trunk in the sagittal plane will be greatest during all three phases for the single leg techniques, followed by the double bent leg, with the least change in neck position occurring in the double straight leg position.**

1. **The dependant measure in question for this hypothesis is a measurement that defines the bending moment about C4. The greater the deviation from 180 degrees, the less mechanically ideal the posture will be.**

iii. **COP deviation from the center of the base of support will be greatest during all phases of Sirsasana for the single leg techniques, followed by the double bent and then even less for the straight leg technique.**

1. **The dependant measure in question for this hypothesis is the center of pressure in terms of x and y coordinates on the force plate. Deviations from a central point indicate leaning and instability in the posture.**

IV. **Background and Significance**:

According to a 2008 study conducted by *Yoga Journal*, 6.9% of adults in the United States alone participate in some form of yoga. Whether or not these individuals are coming to the mat for strength, flexibility, stress-relief or meditative purposes, they will all be walked through similar, if not the same, asanas, or postures, on the way to their particular brand of enlightenment. Headstand, known to those in the yogic-know as Sirsasana, is classically referred to as "the king of all asanas" and is often a climactic moment in a public yoga class. During one interpretation of this pose, the practitioner places the crown of the head and forearms down on the floor, hands interlaced behind the head and lifts the feet towards the ceiling without outside support. What has 15.8 million people popping up atop their forearms and heads on a regular basis? It's the promise of a better body and a better life. Headstands are anecdotally purported to combat depression, improve memory, alter mood, aid circulation, and strengthen various muscle groups. The list does not stop there.

And then, of course, there are the risks. In the same breath that a yoga instructor gives the pros, he or she will also call out a list of the cons, or contraindications. Instructors are trained to warn students with glaucoma, detatched-retina, or high blood pressure not to go upside down. Pregnant women or women on their menstrual cycle are given a heads up as well. By the time the teacher starts talking about allergies, ear infections and forward head position, he or she is beginning to sound like a legal disclaimer. By that time, many eager students have already taken the plunge, head first. Is there a more pressing matter that they need to know?

Despite the fact that yoga asanas have been around for thousands of years, there is relatively little research on them. In the case of Sirsasana, a handful of studies have been done. While headstand was found to temporarily lower heart rate and increase sympathetic vasomotor tone (Manjunath NK & Telles S., 2003), most of the studies that have been conducted relate to glaucoma and intraocular pressure. In 2006, a study concluded that intraocular pressure doubled during the execution of a headstand (Baskaran M et al., 2006). That particular study did not find a correlative effect between headstand and progressive glaucoma but others conducted since have concluded otherwise (Gallardo et al., 2006). It was also found that patients with congenital glaucoma might suffer from progressive glaucomatous optic neuropathy by spending time in the "king of all asanas" (de Barros et al., 2008). A case study of a man who suffered central retinal vein occlusion and vision loss after performing sirsasana (Shah NJ, & Shah UN., 2009) was the last published research looking into the matter of looking at the world upside down. In short, no research has been done on the biomechanics of headstand.

There are a number of ways to get into a headstand and there are actually a number of variations but every single one of these techniques starts with a head being placed on the floor. In essence, the neck becomes the body's new set of ankles. Is a body part typically enrolled to carry a six or so pound mass prepared to do all of that heavy lifting? Students are assured that this unnatural activity is safe because the arms bear the brunt of the weight. This may be true for advanced students but even so the process of take off and landing necessitates some transfer of weight into the head. The practitioner's technique plays a role as well. To get airborne some students kick up one leg at a time (single leg), others pick both feet up simultaneously with bent knees (double leg bent) and the most advanced students come up with the legs straight and together (double leg straight). Technique used is determined by level of ability, instruction, and structural limitations. An individual who regularly performs a headstand task typically does so in the same way every time, both on entry and exit, without variation. Most practitioners simply cannot and do not perform all three entry techniques, rather they are more easily able to do one over another or were trained to use a specific technique. Looking at these three very common but distinctly different headstand entries, this study intends to determine the angle and magnitude of the force traveling through the head during notable transitions.

The answer to this question could help millions of yogis avoid a lifetime of neck pain. Protocols based on the results can be developed and brought to associations such as the Yoga Alliance that set the standards for yoga teacher training facilities and therefore affect the teachers who educate the general public. The warnings concerning eye issues and glaucoma are given abundant lip service in the yoga world and their findings are not yet five years old. These findings could bring beneficial results to nearly 16 million Americans in just a few years. Education is everything, and while being upside down may change one's perspective, new information about the forces passing through the head and neck may have some yoga lovers changing their minds.

V. Research Method, Design, and Proposed Statistical Analysis:

A. Methods:

Participants will make one visit to the Developmental Motor Control Lab (546B Belmont). Upon arrival at Belmont, they will be met by one of the researchers, and escorted up to the laboratory space. The experimenter will review the contents of the consent form with the subject, have them sign if they are willing, and provide them with a personal copy for their records. Subsequently, the subject will be given a questionnaire concerning the nature and duration of their headstand capabilities. A measurement of the subject's weight will be taken and recorded on the top of the questionnaire. The questionnaire will not contain their name or other identifying features. Both documents will be confidential and will only be accessible by the primary investigator along with other individuals who assist in the experimental process.

The subject will then be asked to complete a timed ten-minute warm-up. The warm-up period is yoga-specific but is not individually instructed; however, the subject must complete the warm-up on their own yoga mat, which they were asked to bring. This is included to simulate common conditions and to ensure further safety of the student during performance of inversions as it is typical to warm-up prior to their completion. After the warm-up, 18 infrared sensors for the Vicon motion capture system will be attached to the subject. Upon initial phone or email contact, the subject will be asked to wear tight-fitting non-reflective clothing, their hair up and out of their face and no jewelry. Failure to meet these requirements will be addressed prior to the attachment of the markers as they will interfere. Loose fitting clothes will be secured with foam medical tape. When the subject has met the above requirements, pre-prepared markers will be applied to the following locations: right earlobe, left earlobe, chin, forehead, right elbow, left elbow, right shoulder, left shoulder, C4, C7, T9, L5, Right ASCI, left ASCI, right outer knee, left outer knee, base of second toe on right foot, and the base of the second toe on the left foot. None of these markers interfere with regular headstand performance.

After marker placement, the subject will take one stationary trial while standing on a force plate (instrumented scale embedded in the floor). They are asked to stand in a yogic stance: Tadasana or Mountain Pose. A short trial is taken which serves to record their "yogic posturing" and their initial force values. This trial is processed immediately to ensure data capturing systems are functioning properly so as not to discover errors during the more intensive trials. Following this procedure, a 4x6 foot platform covered with a thick yoga mat is placed over the 40x60 centimeter force plate. Three headstand trials are captured with the practitioner placing their head on the location of the platform indicated by a circle. The subject is told to begin when ready and to maintain the pose for five of their breaths, then they can come down. A requisite two-minute rest period is placed between trials to offset the effects of fatigue, anxiety and to further ensure safety. During teach trial, no didactic instruction is given aside from a reassurance that they can come down if needed.

It should be noted that the section of the mat where the practitioner places their head is in full contact with the force plate; however, the section under the arms is floating, held up by rubber "feet" surrounding the plate. The practitioner is not aware of this fact and cannot feel the difference between the free-floating area touching the plate and the area not touching the plate as the gap, cut out of the wood is too small to notice beneath the thickness of the mat. To them, it is a flat, stable surface. The platform rests a total, including the board itself, 1.5 inches above the floor and is larger than a typical yoga practice space. With this method, only the forces about the head are recorded. To monitor that this piece of equipment is working effectively, forces are observed on the computer monitor as the subject puts their forearms on the mat and then their head. The experimenter should see no visible forces when the arms are placed and then see a nominal force when the head is initially situated.

After the third trial, markers are removed (with alcohol rubbing pads if the tape is painful to the subject) and the subject is asked to spend 5 minutes performing a yoga-inspired "cool down" on their own personal mat. During this time, the headstand trials can be processed and capture assured. When ready, the subject is escorted back to the front of the building. Equipment in the lab is put away and the platform mat is cleaned.

B. Design and Statistical Analysis:

This is an experimental project comparing three headstand techniques. These techniques are commonly taught by teachers and/or performed by students in yoga classes. In this study, individuals will perform only one variation of the headstand technique. Thus the statistical design will be a 3x3 RMANOVA with repeated measurement on trial (3 techniques X 3 trials).

We have limited data for establishing power. Presently, it is estimated that 99 subjects (33 per group) will be necessary to find a moderate effect (effect size > .2-).

VI. Human Subject Interactions

A. Sources of potential participants

Participants will be selected on a volunteer basis from members of the Austin yoga community which is currently estimated at 40,000 strong. The subject population will include males and females aged 18 and older. All participants must be able to perform Sirsasana (headstand) without assistance from a wall or teacher and maintain it for 5 self-counted breaths. Individuals reporting previous or current neck pain, trauma or injury will not be considered.

B. Recruitment

Recruitment will be conducted through the local yoga community, via online message boards related to yoga in Austin (such as yahoo groups and facebook groups) as well as from flyer placement at studios and yoga venues (Yoga Yoga, University of Texas gym system). While the experimenter is a current yoga professional and does teach public classes in Austin, she is contractually required not to solicit students in any way during classes including for experimentations sake. That said, the snowball technique will still be used to recruit potential participants beginning with those contacted who show an interest outside of the classroom setting. Flyer can be viewed in Appendix B.

Participants will be recruited based upon their ability to perform headstand for 5 breath cycles; this indicates that each individual is a semi-regular practitioner of the activity. Upon arrival individuals will select their preferred method of entry and will be asked to perform said entry during the experiment. It should be noted that individuals performing headstand tend to do so in the same method each time. In order to collect equal numbers in terms of the three entries, individuals will be asked to reveal their preferred method prior to participation.

C. Procedure for Obtaining Consent

Practitioners will sign a consent form upon their arrival in the lab. They will be given a copy for their records. Minors are not allowed to participate.

D. Research Protocol

Participants will come to the lab for one 60-minute session. Force plate data as well as kinematic data will be collected. The vertical force and the center of pressure data from the force plate collection will be analyzed to determine max load, time of max load and center of pressure at that time. The kinematic data will be analyzed to determine toe off, toe down, and head position during points of interest. The following table describes what will take place during the subject's time in the lab.

Estimated Elapsed Time	**Activity**
00:00	**Arrival:** greet participant in front of building; provide them with a parking pass; escort them to the lab
00:05	**Release Form:** walk subject through the consent form; have them sign; provide a copy
00:10	**Questionnaire:** walk subject through questionnaire; explain that it is anonymous; assign subject a number so that their name and physical information are kept separately
00:12	**Weight:** measure subject's weight on a balance scale and record
00:14	**Warm-up:** subject is asked to spend 10 minutes warming up with yoga exercises on the confines of their personal yoga mat; experimenter prepares markers for subject preparation during this time
00:25	**Subject Preparation:** reflective surfaces on the subject's person are removed or covered; earrings are removed or covered; hair is pulled away from the face and neck; loose clothing materials are removed or affixed to the person with medical tape; 18 markers are applied to the subject
00:32	**Static Stance:** subject is captured standing on the force plate in a static position
00:35	**Headstand:** with platform in place subject performs first headstand, holds for 5 of his or her breaths then comes down
00:36	**Rest Period**: subject rests for 2 minutes
00:38	**Headstand:** with platform in place subject performs second headstand using the same technique as the first, holds for 5 of his or her breaths then comes down
00:39	**Rest Period 2**: subject rests for 2 minutes
00:41	**Headstand:** with platform in place subject performs third headstand using the same technique as the first two, holds for 5 of his or her breaths then comes down
00:42	**Rest Period 3**: subject rests for 2 minutes
00:44	**Cool Down:** subject is asked to return to his or her personal mat and perform five minutes of yoga-related cool down activities
00:49	**Marker Removal:** markers and tape are removed slowly and carefully from the subject

00:54	**Subject Check-In:** Experimenter checks-in with subject to see if he or she has questions or concerns
00:59	**Exit:** subject is escorted to the front of the building and parking pass is retrieved
00:60	**Data Processing:** Experimenter returns to the lab for clean up and data processing

E. Privacy:

Each subject's privacy will be ensured through the use of a private laboratory setting. The investigator, subject, and assisting investigator will be the only individuals present for data collection. Confidentiality of participant information will be ensured by not attaching the subject's name, phone number, or physical measurements to digitized data (computer files). Physical measurements of the participants will only be used to normalize data and report statistical means for the entire group. Personal information obtained, such as name and telephone number, will only be used for scheduling purposes and will not be attached to any data reported.

F. Confidentiality:

Data will be stored on a restricted access lab computer within a locked room. Information will only be accessible to authorized faculty and research personnel. Digital records will be archived in de-identified form. To ensure confidentiality of subject identification, a project code will be assigned to each participant. This protocol will be followed for data collected on and off campus. These data may be used at a later time for additional analyses.

G. Resources:

Research staff will include the primary investigator (Rachel E. Hector), the study supervisor (Dr. Jody Jensen), along with the assistance of research assistants (other graduate students in the Developmental Motor Control Laboratory and undergraduate assistant Fahad Sharwani). Data collection will occur on campus only.

VII. Risks: There is the potential risk of loss of confidentiality. This will be protected by assuring that all information is kept within the laboratory that is accessible to only authorized personnel. These data will be stored on the computer within in the lab that is only accessible through password and username from members of the lab. Further, any data obtained during this study are recognized as non-sensitive data.

When performing an inversion, there is always a risk of falling. This is a risk these practitioners take willingly and frequently in various settings aside from the lab environment. Many practitioners who invert are accustomed to falling and have prescribed methods of doing so. That said, falling is still not ideal and measures will be taken to prevent it. Firstly, a warm-up period is required prior to inversion so that the subject is fully prepared for the activity. Secondly, the subject is not required to remain in the pose and can come down at any time. If a practitioner looks particularly unstable, they will be asked to come down or to remain in a simpler variation. No markers are being placed on surfaces most affected during falls, including the backs of the hands and the toes.

Having been teaching in the public arena for ten years, the lead experimenter has worked with many students who have fallen and has a depth of knowledge as to how to deal with such an incident both psychologically and physically.

Spotting will be made available to all participants.

VIII. Benefits: There are no potential benefits to the subject. However, this line of research may eventually refine and change the way such inverted loading postures are taught and result in a benefit (that of reduced risk of injury) to many people.

IX. Sites: There are no sites associated with this research. All research will take place on the University of Texas campus in Austin, TX.

X. Review: This study will not be under review by another IRB.

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Appendix B

Interested in Yoga?

Beginner and advanced yogis are needed for a research study taking place in Belmont Hall at the University of Texas in Austin.

Help further the science of yoga!

Requirements:

- **18 years or older**
- **Able to do a headstand with a spotter for a minimum of 5 self-paced breaths**
- **No neck injury or pain**
- **One one-hour visit to Belmont Hall for data collection**

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Appendix C

IRB APPROVED ON: 08/22/2011 EXPIRES ON: 08/21/2012
IRB # 2011-05-0004

Title: **Magnitude and angle of load during various entries into Sirsasana (headstand).**

Conducted By: Rachel Hector
Of The University of Texas at Austin:
Telephone: 512-297-4195

Supervised by: J.L. Jensen, Ph.D
*Department of Kinesiology/Belmont 546*J
Telephone: 512-232-2685

You are being asked to participate in a research study. This form provides you with information about the study. The person in charge of this research will also describe this study to you and answer all of your questions. Please read the information below and ask any questions you might have before deciding whether or not to take part. Your participation is entirely voluntary. You can refuse to participate or stop participating at any time without penalty or loss of benefits to which you are otherwise entitled. You can stop your participation at any time and your refusal will not impact current or future relationships with UT Austin or participating sites. To do so simply tell the researcher you wish to stop participation. The researcher will provide you with a copy of this consent for your records.

The purpose of this study is to

- Determine the magnitude of the force and the angle of the force passing through the head during entry into headstand. Three methods of entry will be compared: single-legged, double-legged with knee flexion, and double-legged with full knee extension.

If you agree to be in this study, we will ask you to do the following things:

- Complete a questionnaire
- Warm up
- Wear reflective markers
- Perform 3 headstands, five breaths each

Total estimated time to participate in study is

- 60 minutes

Risks of being in the study

- Any risk associated with participation in this study is comparable to risks associated with your regular practice of yoga, including the potential risk of falling. Any physical activity has the potential to lead to physical injury. However, you are being asked to perform only those postures in which you already have experience.
- Subjects are allowed to come down at any time. Spotting will be made available to all participants and any subject demonstrating an unstable posture will be asked to come out of the pose.
- The activity you perform in this research study presents no more physical risk to you than what you experience each time you engage in yoga. If, however, you experience an injury as a result of study activity, basic first aid (band-aids, ice, compression, etc) will be provided to you. If you are a University of Texas student, you may be treated at the usual level of care with the usual cost for services at the Student Health Center. If you are not a student at the University of Texas, you will be referred to your personal physician. Please note that the University has no program or plan for treatment of an injury or for continuing medical care.

Benefits of being in the study

- There are no known direct benefits.
- Scientific observation of the headstand is minimal. This study aims to provide a baseline

of information about the headstand's impact on the physical structure; therefore, information obtained may be of future use to the yoga community at large, resulting in fewer neck injuries and a safer, more enjoyable yoga practice.

Compensation:

- None.

Confidentiality and Privacy Protections:

- The data resulting from your participation may be made available to other researchers in the future for research purposes not detailed within this consent form. In these cases, the data will contain no identifying information that could associate you with it, or with your participation in any study.

The records of this study will be stored securely and kept confidential. Authorized persons from The University of Texas at Austin, and members of the Institutional Review Board have the legal right to review your research records and will protect the confidentiality of those records to the extent permitted by law. All publications will exclude any information that will make it possible to identify you as a subject.

Contacts and Questions:

If you have any questions about the study please ask now. If you have questions later, want additional information, or wish to withdraw your participation call the researchers conducting the study. Their names, phone numbers, and e-mail addresses are at the top of this page.

If you would like to obtain information about the research study, have questions, concerns, complaints or wish to discuss problems about a research study with someone unaffiliated with the study, please contact the IRB Office at (512) 471-8871 or James Wilson, Ph.D., Vice-Chair, The University of Texas at Austin Institutional Review Board for the Protection of Human Subjects at (512) 471-6978. Anonymity, if desired, will be protected to the extent possible. As an alternative method of contact, an email may be sent to orsc@uts.cc.utexas.edu or a letter sent to IRB Administrator, P.O. Box 7426, Mail Code A 3200, Austin, TX 78713.

You will be given a copy of this information to keep for your records

Statement of Consent:

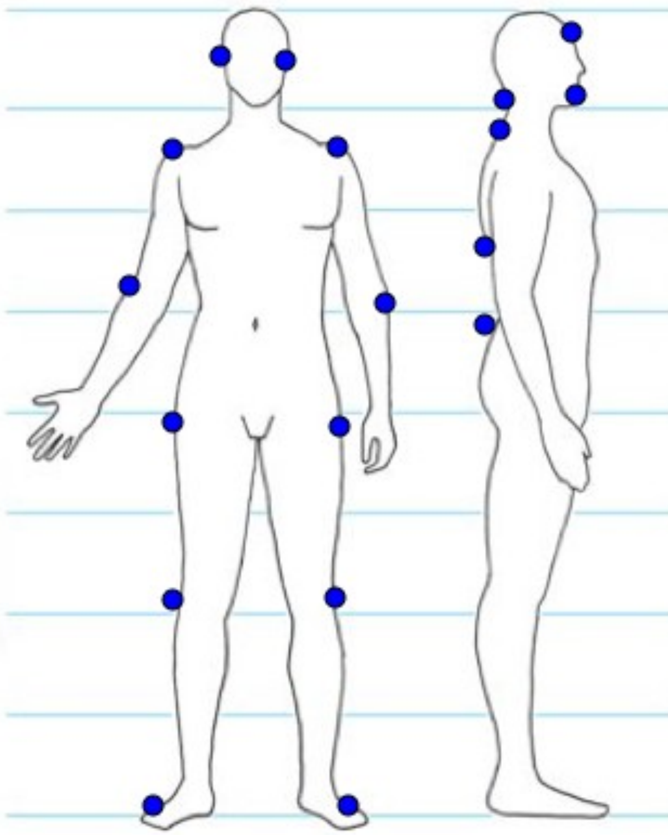
I have read the above information and have sufficient information to make a decision about participating in this study. I consent to participate in the study.

Signature:____ Date: __________________

____ Date: ___________________
Signature of Person Obtaining Consent

Signature of Investigator:__________________________ Date: __________________

Appendix D



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