TIME VARYING GENDER AND PASSIVE TISSUE RESPONSES TO PROLONGED DRIVING

By

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Abstract

Background: Prolonged sitting in an automobile seat may alter the passive tissue stiffness of the lumbar spine differentially in males and females. Gender specific ergonomic interventions may be indicated for the automobile seat design.

Purpose: To compare time-varying passive lumbar spine stiffness in response to a two hour simulated driving trial with time-varying lumbar spine and pelvic postures during sitting in an automobile seat. A secondary purpose was to investigate gender differences in lumbar spine stiffness, seat/occupant pressure profile, discomfort rating and posture.

Methods: Twenty (10 males, 10 females) subjects with no recent history of back pain were recruited from a university population. Participants completed a simulated driving task for two hours. Passive lumbar range of motion was measured on a customized frictionless jig before, halfway through and at the end of the two-hour driving trial. Changes in the passive moment-angle curves were quantified using the transition zone slopes, breakpoints and maximum lumbar flexion angles. Lumbar spine and pelvic postures were monitored continuously during the simulated driving trial with average and maximum lumbar flexion angles as well as pelvic tilt angles being calculated.

Results: Both men and women initially demonstrated an increase in transitional zone stiffness after 1 hour of sitting. After 2 hours of sitting, transitional zone stiffness was found to increase in males and decrease in females. During sitting, women were found to sit with significantly greater lumbar flexion than males and to significantly change the amount of lumbar flexion over the 2 hour period of simulated driving.

Conclusions: Postural differences during simulated driving were demonstrated between genders in this study. In order to prevent injury to the passive elements of the spine during prolonged driving, gender specific ergonomic interventions, such as improved lumbar support, are indicated for the automobile seat.

Keywords: Lumbar spine, low back, gender, sitting, driving, stiffness, ergonomics, injury prevention.

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Chapter 1 Introduction

According to the 2005 Statistics Canada General Social Survey, Canadians spend increasingly more time commuting to work; on average 63 minutes round trip. For professional drivers, such as truck drivers and police officers, driving time per day can exceed eight hours. According to the Highway Traffic Act (Ontario Regulation 555/06) the maximum legal hours of service for truck drivers is 13 hours of driving per day. Thus, driving for extended periods of time is a reality for a large portion of the population.

Sitting for prolonged periods of time in a vehicle has been identified as a potential cause of mechanical low back pain in the literature (Frymoyer et al. 1980). In general, when adopting a seated posture the pelvis rotates posteriorly and the lumbar lordosis flattens out. This increases pressure in the posterior aspect of the discs of the spine as well as strain in the posterior passive elements of the spine (Keegan, 1953, Andersson, 1974).

There is evidence in the literature that men and women adopt different lumbar spine and pelvic postures in both office chairs and automobile seats (Dunk et al., 2005, Gregory et al., 2006, Beach et al., 2008). Adopting these different postures seems to provoke a different response from the passive elements of the lumbar spine in an office chair (Beach et al., 2005). This thesis will explore passive lumbar spine stiffness in response to prolonged sitting in an automobile seat as well as further explore the gender differences in posture observed in earlier studies.

The effect lumbar spine and pelvic postures have on the passive elements of the lumbar spine during prolonged driving is a valuable contribution to our understanding of spine biomechanics and injury prevention. Further, research exploring the gender differences in sitting is necessary to improve the current design of automobile seats such that they adequately support all occupants.

1.1 Investigative Purpose

The primary purpose of this study was to investigate the time-varying passive flexion stiffness response of the lumbar spine to prolonged sitting in an automobile seat. Secondary purposes were to determine whether or not gender differences exist in passive stiffness response, lumbar spine and pelvic postures, perceived discomfort or seat/occupant pressure profiles during simulated driving.

1.2 Hypotheses

It was hypothesized that time-varying changes in lumbar spine stiffness would be observed during prolonged simulated driving due to the relatively constrained flexed postures imposed by automobile seats. Based on the findings of Coke et al. (2007), it was also expected that gender differences would be found in lumbar flexion angle and pelvic posture in sitting. Specifically, it was expected that female subjects would have a greater amount of lumbar flexion and a more posteriorly rotated pelvis than males. Consequently, the main hypothesis of this study was that lumbar spine stiffness would decrease over time in females compared to males as a result of prolonged increased flexion. It was also hypothesized that perceived discomfort would increase over time and that seat pressure profiles would reflect participants “sinking into the seat”, increase in total area and anterior and superior movement of seat pan COP and backrest COP respectively, as seen in previous studies.

Chapter 2 Review of Literature

2.1 Low Back Pain

Low back pain is one of the most perplexing musculoskeletal conditions affecting society. While some mechanisms and risk factors have been identified, researchers are still unable to predict exactly who will develop back pain. From epidemiological studies it has been determined that there is a 50-80% lifetime chance of developing low back pain (Biering-Sorensen et al., 1989). It is also estimated that in any given year, 25-45% of the population will be afflicted with a back condition of some kind (Kesley et al., 1953). The extensive effects of this condition on the population are reflected in the workforce. It is well known that low back pain is one of the most common reasons for absence from work and decreased productivity in the United States (Wilder et al., 1996). It is also a leading cause of worker's compensation claims and has been determined to be the 4th most costly physical health condition affecting American businesses (Goetez et al., 1999).

2.2 The Lumbar Lordosis

At birth, the infant spine is completely convex posteriorly or kyphotic. Toward the end of the first year, as developmental milestones such as lifting the head and standing upright are reached, three natural curvatures develop: a concave cervical lordosis, a convex thoracic kyphosis and a concave lumbar lordosis (Willis, 1944, Epstein, 1955). In the upright position, these curves are very important for absorbing vertical loads imparted on the spine in a manner that minimizes the stress and strain on both the anterior intervertebral discs and the posterior joints of the column. In a paper entitled, "The development of the lumbar lordosis," Reichmann and colleagues (1971) describe their work on the excision of cadaver lumbar spines from 173 donors ranging in age from 0-25 years old. The authors found that the lumbar curvature eventually develops even in bedridden individuals. Therefore, while most literature points to the influence of resisting gravity in the upright posture as the driving force for the development of the lumbar lordosis, Reichmann et al. (1971) concluded that alternative mechanisms, most notably hip extension when lying supine, can also result in the development of this curve. This study points to the importance posture and muscular tension have on the lumbar curve in other postures besides standing.

There is a differential amount of involvement of the lumbar vertebrae in the lumbar lordosis. Researchers have found that approximately 66% of the lumbar lordosis is made between the lower three lumbar vertebrae, from L4-S1 (Bernhardt and Bridwell, 1989, Stagnara et al., 1982 and Jackson et al., 1994).

Many authors have suggested that the lumbar lordosis has a protective effect on the structures of the spine. In a study examining cadaver specimens, Farfan et al. (1972), noted an association between decreased lumbar lordosis and disc degeneration at the L5/S1 intervertebral disc level. Intradiscal pressure has been shown to be inversely proportionate to the degree of lumbar lordosis (Andersson et al., 1975, Adams and Hutton, 1985). Less muscular effort from the back extensors are required to support the vertebral column when the lumbar lordosis is maintained. Corlett and Eklund (1984) explain this benefit of the lumbar lordosis as a result of keeping the lower vertebrae close to or directly under the center of gravity of the upper body.

2.3 Measurement of the Lumbar Posture

External measures of the lumbar lordosis have included a number of different techniques such as simple bendable rulers (Youdas et al., 2006), strain gauges in a tape like device (Carcone and Keir, 2007), inclinometers (Adams et al., 1986), accelerometers (Hansson et al., 2001), and optical devices such as the “spine mouse” (Mannion et al., 2004) in addition to the more traditional optical or electro-magnetic based motion capture systems. Currently, these alternative approaches to obtain external measures of lumbar lordosis angle and pelvic tilt have demonstrated limited validity when compared to concurrent radiographic measures. For example, while instruments such as a flexible ruler might seem like an attractive tool to assess spinal curvature, recent literature (Harrison et al., 2005) has documented limited intra-rater reliability with interclass correlation falling in the poor or fair range when repeated measures of cervical spine curvature were taken by three examiners. In a second study, the flexible ruler was found to have poor concurrent validity for the measurement of cervical spine curvature when compared to lateral cervical spine radiographs (Harrison et al., 2005).

Electronic devices such as inclinometers and uni-axial accelerometers have demonstrated improved approximations of radiographic measures (Adams et al., 1986). These instruments are limited by a significant amount of experimental error such as small ranges of measurement, steps in output angles, measurement about the orthogonal axis of the device and degradation of the signal as the inclination surpasses 60˚ in either direction (Otun and Anderson, 1988). In a study investigating the range of motion and lumbar lordosis of the lumbar spine, Ng et al. (2001) found inclinometer measures of the lumbar lordosis to vary between 23˚ and 33˚. Mannion et al. (2004) tested a new skin surface mouse-like electronic device that is capable of measuring the overall curvature and ranges of motion of specific parts of the spine. Their study found an average lumbar lordosis of 32 degrees.

In quasi static situations such as quiet sitting, tri-axial accelerometers can be used as extremely sensitive tilt sensor that will output a linear acceleration that when compared with respect to gravity can be transformed into an angle with respect to the vertical without the limitations of inclinometers or uni-axial accelerometers (Hansson et al., 2001). There has yet to be a study to date that has validated the use of tri-axial accelerometers to measure the lumbar lordosis or pelvic tilt against a concurrent radiographic measure.

There are a number of obvious problems with external measures of lumbar lordosis. The most notable are the potential for skin movement over bony landmarks, loss of contact with the back during testing, amount of subcutaneous fat and inaccuracies in surface anatomy palpation (Manion et al., 2004). Furthermore, the use of a backrest, especially in the automobile seat, negates the use of many external measurement systems due to lack of line of sight, movement of the device with respect to the skin or loss of contact over time due to friction.

2.4 Gender Differences

Gender differences in the prevalence of low back pain have been reported by Le Resche et al. (2001) who found a prevalence ratio of 1.2:1 between women and men.

There are a number of definite differences between the bony anatomy of the male and female pelvis (Van der Graaff, 2002). Specifically, the male pelvis is larger, has more prominent bony features, a narrower heart shaped pelvic inlet, a narrower distance between anterior superior iliac spines, oval obturator foramen, laterally facing acetabulum and a narrower pelvic arch. The female pelvis is smaller, has less prominent bony features, a wider oval pelvic inlet, wider distance between anterior superior iliac spine, triangular obturator foramen, more anteriorly facing acetabulum and a wider pubic arch (Van der Graaff, 2002). From a structural point of view, this gives the male pelvis a smaller base of support due to the closer proximity of the ischial tuberosities. Considering the great influence the pelvis has on the posture of the lumbar spine, it is reasonable to assume that these integral anatomical differences will lead to biomechanical differences in the way men and women sit.

There is some controversy in the literature regarding gender differences in spine and pelvic posture. In upright standing, most of the literature has found no radiographic difference in the lumbar lordosis or pelvic tilt measurements between males and females (Stagnara et al., 1982, Troyanovich et al., 1997, Vaz et al., 2002, Bernhardt, 1989, Boulay, 2006, Jackson and McManus 1994, Wood et al., 1996 and Voustsinas and MacEwen, 1986).

There are, however, research groups that have found significant differences between the measured lumbar lordosis and pelvic tilt between genders. In a prospective and retrospective study, Fernand and Fox (1985) measured a mean lordosis from L2 to S1 of 45 degrees in the recumbent position of 416 women and 330 males. An average difference of four degrees was found between men and women, with women having a slightly greater lumbar lordosis than males. Vialle et al. (2005) found females to have a five degree increase in mean lumbar lordosis angle compared to men. In both studies pelvic tilt was not found to be significantly different. Hanson et al. (1998) found statistically different lumbosacral and sacral tilt angles between black and white subjects. Specifically, black males were found to have a mean lumbosacral angle of 9.4º (+/- 3.4º) compared to 5.1º (+/-0.3º) in white males. Black female subjects were found to have a mean lumbosacral angle of 13.1º (+/-0.5º) compared to white female subjects 9.2º (+/- 0.6º). Mean sacral angle was 43.6º (+/- 3.4º) in black males compared to 61.7º (+/- 2.1º) in white males and 36.0º (+/- 2.2º) in black females and 50.2º (+/-1.9º) in white females. The authors did not report whether or not results were significantly different between genders. Measurements taken in this study were completed on cadavers with an external measurement device.

Preliminary research in our laboratory has found gender differences in lumbar and pelvic posture during sitting in both office chairs and automobile seats. In an office chair females have a slightly greater lumbar lordosis measured externally, a more vertical trunk and the tendency to sit more upright on their pelvis and to “perch” at the front edge of the seat. Males on the other hand tend to slouch with a more posteriorly rotated pelvis and they tend to sit farther back in the seat (Dunk and Callaghan, 2005). In an automobile seat differences were also found between males and females, however, they were not the same as those found in an office chair condition. Females sat with greater relative posterior rotation of the pelvis than males and used a greater area of the seat pan (Coke et al., 2007).

Beach et al. (2008) investigated the correlation between hip and low back flexibility to lumbar and pelvic postures in the office chair and automobile seat. While not statistically significant, females were found to generally exhibit greater hip and low back flexibility compared to males and tended to sit with greater lumbar flexion during simulated driving. In automobile seats, participants with greater hip flexibility sat with statistically significant greater lumbar flexion. The authors suggested that flexibility may play a large role in the postural gender differences previously seen (Dunk and Callaghan, 2005, Gregory et al., 2006, Coke et al., 2007).

The prominent differences in the lumbar lordosis and pelvic tilt found in males and females when sitting are an intriguing finding. Perhaps the anatomical differences that exist have a more distinct effect on spine and pelvic posture when the pelvis becomes the base of support.

2.5 Sitting

In sitting, the lumbar lordosis tends to flatten and the pelvis rotates posteriorly. This kyphotic posture places increased stress on the posterior elements of the spine and raises intradiscal pressure (Keegan, 1953, Andersson, 1974). Keegan (1953) described the process of sitting in great detail in his article entitled, “Alterations of the lumbar curve related to posture and seating”. According to Keegan (1953), as the lumbar lordosis flattens in sitting, the center of gravity of the upper body is moved anterior to the lumbar vertebral bodies. This creates a perpendicular distance and thus an external flexion moment about the low back. In order to balance this moment, increased tension must be created from the lumbar erector muscles along with support from passive structures, thus increasing the load on the spine. Andersson et al. (1975) found that intervertebral discs become anteriorly wedged in sitting, which places tensile pressures on the posterior aspect of the disc. There are two other ways this load can be supported. First the pressure of the abdominal cavity can be used to support the spine. Second, if a fully slumped posture is adopted the erector muscles will turn off due to relaxation (Callaghan et al., 2001, O'Sullivan et al., 2006). In this position the passive elements of the posterior spine (ligaments) may be capable of supporting the trunk during sitting. In fact, this slumped or "kyphotic" low back posture is frequently adopted. In healthy, low back pain free individuals, it can be maintained for some time without pain. The danger is that these kyphotic postures increase the stress on the posterior fibers of the intervertebral disc and posterior ligaments of the spine as well as increase intradiscal pressure (Keegan 1953, Kottke 1961, Cyriax 1975, McKenzie 1981).

Adams and Hutton (1980) found an increase in compressive forces of 16% when subjects were positioned in forward flexion. Granted, too much lumbar lordosis can create a problem as well by transferring increased force to the facet joints. Increased amounts of time spent in any of these postures are thought to increase risk for the creation of low back pain (Adams and Hutton, 1983). Jackson et al. (1994) found significantly different lumbar lordosis measurements between a population suffering from back pain and a normal population. Back pain sufferers were found to have a lower total lumbar lordosis measurement on average than non back pain sufferers: 56.3˚and 60.9˚ respectively.

In a study comprised of four subjects (2 males and 2 females), Keegan and Nebraska (1953) took lateral lumbar radiographic films of the subjects in different functional positions from standing to sitting. Tracings were made from each sequential film by outlining the posterior aspect of the vertebral bodies forming lumbar lordosis with the sacrum superimposed. These tracings were analyzed subjectively. Unfortunately most of the study design was not standardized and not all positions were used for each subject. Extra recumbent films were taken on one male subject to investigate alterations in the lumbar lordosis when the knee and hip angle are changed. The authors concluded that the normal curve of the lumbar spine in the adult male occurs when the thigh-trunk angle is at approximately 135˚. Therefore, according to Keegan and Nebraska (1953), the most important factor for the generation of low back pain in sitting is the decrease of the thigh-trunk angle and the consequent loss of the lumbar curve.

In a study investigating the influence of back supports on spine posture in upright sitting, Andersson et al. (1979) found an average loss of 38˚ in the lumbar lordosis angle from standing to unsupported sitting as measured on radiographs for 8 subjects (4 female and 4 male). The authors concluded that most of the loss occurred due to an average posterior rotation of the pelvis of 28˚ with the rest of the movement occurring between the L4 and L5 vertebral bodies.

Alexander et al. (2007) examined the lumbar lordosis in six functional positions, from upright standing to fully flexed sitting using MRI. Specifically, the research goal was to quantify the sagittal migration of the nucleus pulposus in the lumbar intervertebral discs in 11 healthy subjects (7 females and 4 males). The researchers found mean lumbar lordosis spine angles to continually decrease from standing to upright sitting to flexed sitting. All positions examined were found to have a significant effect on the position of the nucleus pulposus, with posterior migration of the nucleus occurring as the participant flexed forward.

Lord et al. (1997) used radiographs to examine the lumbar lordosis in both standing and upright sitting with no back support on a stool. The subject population consisted of 70 men and 39 women and radiographs were taken with the subjects in a standardized position: arms flexed forward at 90˚ degrees holding on to a support regardless if the subject was sitting or standing. The lumbar lordosis angle was measured from L1 to S1 and averaged 49˚ degrees in standing and 34˚in sitting. The authors concluded that close to half of the lumbar lordosis on average is lost in the sitting position when compared to standing. Unfortunately, the authors did not look for differences in lumbar lordosis between genders.

Lumbar and pelvic posture in sitting has been shown to affect seat pressure measurements and perception of pain. As the lumbar lordosis decreases in sitting, seat pressure measurements and perception of pain have been found to increase under the ischium and the coccyx (Drummond et al., 1954, Drummond et al., 1982, Shields et al., 1988). Many authors have demonstrated that a change in posture will alter low back and seat pressure measurements (Henderson et al., 1994, Hobson, 1992, Koo et al., 1996). Generally, as the occupant reclines, a greater percentage of bodyweight is supported by the backrest. This will decrease the load transferred through the spine to the pelvis and consequently to the seat pan (Andersson, 1975). In wheelchairs, Koo et al. (1996) found that seat pan pressure was also decreased when occupants adopted a more upright trunk posture as opposed to a forward flexed “slumped” posture.

2.6 Sitting in an automobile Seat

When sitting in an automobile seat, drivers tend to adopt a more posterior sitting posture. This posture, described by Schoberth in 1962, is defined as having a posteriorly rotated pelvis and kyphotic lumbar spine with the center of mass of the upper body falling posterior to the ischial tuberosities. This posture is also thought to increase the strain on the posterior passive elements of the spine. The position of the driver is constrained by the need for continuous attention to the path ahead as well as controlling the vehicle via pedals and steering wheel. Together with the added side bolsters of the vehicle seat, these constraints leave little to no room to modify the posture of the driver (Jones, 1969). Thus, poor posture combined with the effects of vibration and increased driving times have been identified as sources of elevated risk of low back injuries ranging from disc herniations to general muscular soreness (Kelsey 1975, Magnusson et al., 1996, Wilder et al., 1982, Bovenzie et al., 1992, Porter et al., 2002, Frymoyer et al., 1980).

Increased seat pressure over time has been shown to correlate with increased discomfort and reduced concentration when driving (Moes, 2007). As an individual sits for a prolonged period of time in an automobile seat, compression of the soft tissues and seat foam increase as reflected in an increase in total seat pressure. Compression of the soft tissues increase the hydrostatic pressure and shear stress at the buttock seat interface and have been shown to have a negative effect on capillary blood flow, nerve conduction and interstitial fluid movement all which may be sources of discomfort (Chow and Odell, 1978, Oomens et al., 1987, Levine et al., 1990).

2.7 Car Seat Design

In order to ensure the safety and comfort of the occupant, there are a number of design considerations that must be made with respect to the automobile seat. The seat should provide: adjustments to accommodate anthropometrics, enough support such that the occupant has clear visibility and access to all controls, protection against vibrations in the 4-10 Hz range, and soft enough seat material to provide comfort yet stiff enough to provide protection in a high impact collision (Katsuraki et al., 1995, Wilder et al., 1982).Unlike the office chair, where the occupant can support a portion of their bodyweight by their feet, in the automobile, the seat must provide total support in order to free the legs and feet to control the pedals (Andreoni et al., 2002). To accomplish this, the seat pan and backrest in most vehicles have a slight posterior angulation or tilt to keep the occupant in full contact with the seat and balanced while driving and aid in retaining the occupant in the seat during a crash.

In order to encourage optimal spine posture while driving, many automobile seats include a convex support in the lower region of the backrest. The purpose of the shape is to fit into the occupant's lumbar lordosis and minimize loss of contact between the seat and the lumbar spine and pelvis (Reed and Schneider, 1996). However, if allowance for adjustment is not made, it is unlikely that this profile will match the concavity of lumbar spine for a sizable proportion of the general population. Indeed, when studying the effect of lumbar supports on occupant posture in a minivan, Reed and Schneider (1996) found that on average, subjects' lumbar lordosis did not fit properly into the lumbar support provided by the chair and that discomfort may result from pressure points or lack of support at the levels of the spine where the profile does not match. Porter and Gyi (2002) also noted a correlation between lack of seat adjustments and incidence of low back pain in drivers. Therefore, in order to accommodate for anthropometrics and variability in the sagittal spine profile, Reed and Schneider (1996) concluded that automobile lumbar supports need to be completely adjustable in addition to the standard adjustments for the backrest, seat angle and distance from the steering wheel.

2.8 Function of a Seat Backrest

A backrest functions to support a portion of the occupants' weight during sitting. When using a backrest, the mid and upper back is able to tilt posteriorly, consequently compensating for the backward rotation of the pelvis and minimizing the kyphosis of the lumbar spine in sitting (Keegan, 1953, Zacharkow, 1988). In this position, the erector muscles of the spine are not required to maintain the posture and thus they only need to turn on to provide intermittent support to correct the sway of the body above the highest level of the backrest (Corlett et al., 1984). In their paper outlining the importance of backrest use, Corlett and Eklund (1984) describe how use of the support brings the center of gravity of the upper body over the lumbar spine. This allows force due to gravity to be transferred to the seat as opposed to being counteracted by the muscles of the back. By leaning on the backrest, pressure in the abdomen is decreased as the thigh-trunk angle is increased (Keegan, 1953). Andersson et al., (1975) also measured decreased pressure in the intervertebral disc when a backrest was employed and noted a backrest angle of 100° as the best angle to minimize intradiscal pressure. Driving tasks such as shifting gears and clutch pedal depression were found to cause large increases in intradiscal pressure which were partially relieved by an increased seat back angle.

2.9 Lumbar Support

Despite the inability to change postures, interventions such as lumbar supports have been shown to relieve some of the discomfort associated with automobile seat sitting. A lumbar support can be described as a convex contour of a chair in the region of the lumbar spine, which fills the convexity of the spine to provide support. This support can be as simple as extra padding or as complex as a motorized unit capable of movement in both the horizontal and vertical axes. The addition of a lumbar support to a seat has been suggested by various authors as an approach to prevent the flattening of the lumbar lordosis in sitting (Keegan et al., 1953, Schoberth, 1962).

In a study comparing the effects of a kyphotic versus lordotic lumbar spine during sitting in a population suffering from mechanical low back pain, maintenance of the lumbar lordosis with the use of a lumbar support decreased back and leg pain and aided in the centralization of pain (Williams et al., 1998).

Qualitative studies have found increasing backrest inclination and the use of lumbar supports are associated with decreased reports of low back pain associated with driving on questionnaire responses of professional taxi drivers (Chen et al., 2005). Lumbar supports have been quantitatively found to increase the lumbar lordosis in upright sitting in office chairs and wheelchairs (Makhsous et al., 2003, Lin et al., 2006) and to decrease peak pressure under the ischial tuberosities in automobile seats (Makhsous et al., 2005, Lin et al., 2004).

One problem with this design intervention is ensuring they provide enough support. Reed and Schneider (1996) suggested the supply of extra cushioning in the region of the lumbar spine alone will limit who can benefit from the added support. Heavier occupants are more likely to fully compress this extra material without deriving any supportive benefit. Thus, a motorized lumbar support capable of horizontal excursion is more likely to provide a benefit to the whole population rather than just extra cushioning alone.

Recently, Aota et al. (2007) conducted a study examining the effectiveness of a continuous passive motion lumbar support device compared to no support or fixed lumbar support conditions during two hours of prolonged automobile sitting over three consecutive days. The outcome measures of this study included visual analog scales of discomfort, low back stiffness, fatigue and numbness. The authors found significant decreases in perceived low back pain, fatigue, stiffness and buttock numbness with both a fixed lumbar support and a continuous passive motion device compared to the no support condition.

2.10 Sitting and Comfort

In the automobile there are several design features that can influence occupant comfort. The most important include seat contour and seat foam properties such as deformation over time and stiffness. Chaffin and Andersson (1984) identified adequate back support and allowance for movement as two of the most important considerations in seating. While padding is necessary to avoid localized pressure for comfort, too much padding and cushioning could decrease the ability to change positions, thus a trade off exists (Jones, 1969). Since the chair provides direct support of the occupant, the amount of this support can be determined by the seat pressure distribution. Jurgens, in 1969, concluded that analysis of the automobile seat pressure distribution is an integral part of any automobile seat assessment.

From the literature on spinal cord injuries and wheelchair comfort, it is known that areas of high pressure sustained over a long period of time are associated with skin breakdown (Hackler, 1977, Geisler et al., 1977, El Toraei and Chung, 1977, Constantian, 1980). Due to its subjective nature, quantifying discomfort based on seat pressure measurements has proved to be a daunting task. Further, a difference has been found between short term (fifteen minutes) and long term (greater than one hour) perceived comfort in an automobile seat (Gyi and Porter 1999, Reed et al., 1991), thus testing period lengths are an important component of an effective estimate of comfort.

A number of research groups have found some a relationship between comfort and pressure distribution (Gyi and Porter, 1999, Reed et al., 1991, Thakurta, 1995, Inagaki, 2000 and Hartung, 2005). While a definitive comfort threshold has not been determined, general conclusions regarding comfort and pressure distributions have been made in the literature. In a study examining comfort in automobile seats, Kamijo et al. (1982) concluded that the most comfortable automobile seats are those with pressures ranging from 22.07-36.78 mmHg in the seat pan and 11.03-17.65 mmHg in the backrest. Similarly, Maurer et al. (2004) concluded seat pressure profiles equal to or less than 30 mmHg with an even pressure distribution are most comfortable. A study examining tractor seats reached a similar conclusion that lower pressure profiles are associated with improved ratings of subjective comfort (Tewari and Prasad, 2000). Therefore, while much work is still necessary to understand and predict the relationship between occupant seat pressure and perceived comfort, rough guidelines are in place to assist the automotive industry in the design of more comfortable car seats.

2.11 Prolonged sitting

Sitting for prolonged periods has been associated with an increased incidence of low back pain (Magora, 1972) regardless of whether or not the individuals currently suffer from low back pain (Damkot and Pope, 1984, Majeske, 1984). In fact, prolonged sitting has been found to generate pain in subjects that have no history of chronic back pain (Andersson et al., 1991, Reinecke et al., 1985).

Subtle changes in posture occur slowly when sitting for an extended period of time (Beach et al., 2005). Therefore, to capture these time-varying events it is necessary to collect data for a minimum of one hour (Gyi and Porter, 1999). From this point on, changes in seat pressure distribution and whole body posture become more prominent thus strengthening the data set. In the literature, two hours is regarded as an acceptable length of time for data collection to recreate the prolonged sitting environment experienced by many people in everyday life. With respect to perceived discomfort and seat pressure distribution, the Vehicle

Ergonomics Group has found that at least two hours is necessary to clearly assess the performance of an automobile seat (Gyi and Porter, 1999).

When examining the time varying changes in lumbar spine stiffness during prolonged sitting in an office chair, Beach et al. (2005) generated passive lumbar flexion moment-angle curves before, during and at the end of a two hour sitting trial. The authors found that over the two hour period stiffness increased initially and then decreased in male subjects and was variable in female subjects. Of particular note, however, is that the changes in the male participants did not begin until after the first hour of collection. These changes in stiffness over a two hour period of prolonged sitting in an office chair strongly suggest that there are time-varying alterations in spine and pelvic posture.

2.12 Prolonged Driving and Back Pain

Sitting both in the office and in a vehicle has been identified as one of the risk factors for the development of low back pain (Frymoyer et al., 1980). In this situation, the natural concave curve of the lumbar lordosis becomes flattened, placing stress on the posterior passive elements of the spine. Prolonged static sitting reduces the blood flow to the lumbar muscles, resulting in fatigue and irritation (McGill et al., 2000). This posture has also been found to decrease the flow of nutrients into the intervertebral discs and increases the risk of disc herniation (Kelsey and Hardy, 1975). Many authors have suspected poor postures as the cause of low back pain found in sedentary workers (Eklund, 1967, Hult, 1954, Kelsey 1975, Lawrence 1977, Magora 1972, Majeske and Buchannan 1984). Specifically, the kyphotic lumbar posture when adopted for long periods of time has been found to be closely associated with low back pain (Keegan, 1953, Kottke 1961, Cyriax 1975, McKenzie, 1981).

Damkot et al. (1984) identified the inability to change position while sitting as a major factor in the development of low back pain. Ergonomic studies of the office setting have found that elements that encourage movement such as adjustable seatbacks, seat pans, arm rests and tilt mechanisms and administrative changes such as increased rest breaks and cycling of postures can minimize discomfort and stress to the body during sitting (Corlett, 2006). Unlike in an office chair, constraints such as use of the pedals, steering wheel and gearshift minimize the amount of movement and postures that can be adopted while driving. In a review of literature, Lyons (2002) noted that professional drivers, who drive as part of their work, spend more time sitting in their vehicle than the average population. For this population, the driving compartment of the vehicle often serves as an office where a large portion of time is spent simply sitting in the vehicle and not driving. In the limited space of the driver compartment, it is expected that awkward postures such as slumped sitting, leaning to one side, bending and reaching will be assumed frequently (Lyons, 2002). These positions place extra stress on the soft tissues and joints of the spine and can be a factor in the generation of pain. It is not surprising that professional drivers are estimated to be from 1.6 to 2.0 times greater risk for developing back pain compared to the general population (Liira et al., 1996, Guo et al., 1995).

Several authors have attempted to identify optimal vehicle seat parameters to reduce the likelihood of developing low back discomfort while driving. Andersson et al. (1975) studied four adult subjects in a fully adjustable Volvo car seat. Three parameters: seat back inclination, seat bottom inclination and lumbar support were considered. EMG activity recorded in erector spinae muscles (levels C4, T5, T8, T10, L1 and L3) and the trapezius muscle bilaterally were minimized implying reduced risk of fatigue and pain when the following conditions were met: the backrest was reclined 100º with respect to the seat pan, a horizontal lumbar support of 5cm depth was present and the seat pan was tilted 14° above the horizontal. Harrison et al. (2000) conducted a detailed review of literature to determine the best configuration for the vehicle seat in order to minimize discomfort and injury. The concluding recommendations from this study suggest an adjustable seat reclined at least 100° from the seat pan, adjustable seat depth, adjustable seat bottom incline, firm foam in seat bottom cushion, both a horizontally and vertically adjustable lumbar support, adjustable arm rests, adjustable head restraint, able to dissipate seat shocks in the 1-20 Hz range and sagittal adjustment of the seat forwards and backwards to reach the pedals. This study also suggested the benefit of a pulsating lumbar support to decrease static load and a damped seat back to minimize rebounding of the torso in collisions. Krause et al. (1997) found, in a study of urban transit drivers, that the size of the driver and the degree of adjustability of the drivers' seat were the most likely factors to determine the likelihood of awkward postures during a driving task. By increasing the adjustability of the driver seat compartment it would be possible to accommodate a larger range of the population comfortably and safely.

Chen et al. (2002) examined whether seat inclination and lumbar support use were associated with the prevalence of low back pain in a study of taxi drivers in Taipei. Epidemiological and biomechanical methods were used in this study in an attempt to harmonize the discrepancy concerning low back pain and sitting in the workplace. Registered male taxi drivers who were still actively driving and operating vehicles made by Toyota, Nissan, Honda or Ford were recruited for the study (247 total). On average they drove 9.7 hours per day and had been taxi drivers for over 9 years. Subjects who experienced back pain before they started working as a taxi driver were excluded from the study. Seat pan angle measured from the horizontal and backrest angle from the vertical were collected by digital inclinometer in each of the subjects' vehicles in order to calculate the seat pan-backrest angle. Since these measurements were taken while the subject was seated in the vehicle the authors were confident that the seat pan-seatback angle would be a valid estimate of the thigh-back angle of the subject. The epidemiological part of the study consisted of a structured interview that gathered information on demographics, driving habits, use of a lumbar support and perceived discomfort. The authors conducted a multiple logistic regression in order to estimate the prevalence of low back pain associated with different angles of the seat pan, back rest, estimated back-thigh angle as well whether or not the subject used a lumbar support. Mean seat pan angle was found to be 14.5º above the horizontal, mean seat back angle was found to be 95.1º from the seat pan and 45% of subjects were found to use a lumbar support. An increase in low back pain prevalence was found in subjects who sat with back-thigh angles of less than 91º. Prevalence of back pain was also increased for those drivers not using a lumbar support.

In a 2006 study of medical representatives with prolonged exposure to driving for work, Sakakibara et al. found that total mileage driven is positively correlated with self-reported low back pain. Participants were excluded from this study if they experienced back pain before working with this company. Subjects were divided into two groups: those reporting back pain at the time of survey and/or whose back pain is made worse by driving and a second group including participants without back pain and/or who are not aggravated by driving. Each group was surveyed to determine factors that were linked with back pain. The factors collected in this study included: age, smoking, miles driven regularly, BMI, subjective sitting posture (straight, slightly slouched, and fully slouched), an estimate of back rest inclination, knee angle and the type of transmission of the car. The subjects were also asked questions to qualify the severity of back pain. There was a 92% response rate for the survey. Mean age of participants was 35.7

(range 22-58) and significantly more male than female subjects were used in the study (530-21). Of the 551 people who responded, 53% had back pain and 47% did not have back pain at the time of the survey. The point prevalence of low back pain in this subject pool is slightly higher than is to be expected in the general population (Kesley et al., 1975). Eighty-four people reported experiencing back pain before they started to work for this company and were excluded from the study. There were no significant differences in age, height, duration of employment with the company, estimated daily mileage or type of roads traveled between the two groups; however, total driving time was found to be higher for the back pain group. While this was not substantiated with actual measurements, subjects in the pain free group reported keeping their seat back reclined past vertical. The authors concluded that taking rest days from driving was an important factor in decreasing the incidence of back pain from driving. The cross-sectional design of this survey based study and the reliance on subjects to recall and report specific information such as seat inclinations were both major limitations to this study.

A large cross-sectional interview based survey of high to low mileage drivers at a motor stop in Britain was conducted by Porter and Gyi in 2002. Both professional and non-professional drivers were included and the Nordic Musculoskeletal Questionnaire (NMQ) was used to quantify musculoskeletal problems (Porter et al., 2002). Results from the survey found that an increased exposure to driving and increased driving times were associated with lost time from work due to back problems as qualified by the NMQ. Drivers in cars with more adjustability were associated with lower reports of discomfort and lost time from work. A reported history of back pain was found to be predictive of future occurrences. A main recommendation by the authors is that management personnel responsible for the maintenance and administration of professional drivers and fleet vehicles should be educated in the importance of adjustability when replacing fleet vehicles. Drivers in these companies should also be provided with additional ergonomic education to encourage posture cycling and frequent breaks.

2.13 Viscoelastic Creep

It has been shown in the literature, that the posterior ligaments of the spine, which oppose flexion, can experience viscoelastic creep in response to sustained flexion (Adams and Dolan, 1996, Hedman and Fernie, 1995, Twomey and Taylor, 1982, McGill and Brown, 1992). Creep is defined as the mechanical phenomenon of sub-failure deformation in response to a constant force (Twomey and Taylor, 1982). Adams and Dolan (1996) discuss prolonged sitting as a potential circumstance for ligamentous creep. However, the authors suggest that due to support provided by a chair this creep would eventually relax and not be as dangerous as a prolonged stooped posture as in gardening (Adams and Dolan, 1996). Previous research has shown that prolonged sitting in an automobile seat will result in the occupant essentially “sinking into the chair” over time shown by an increase in total seat pressure area and a decrease in peak pressure as measured by pressure mapping devices during simulated driving (Coke et al., 2007). Thus it is reasonable to assume that in a vehicle, more viscoelastic creep would be possible due to this time varying decrease in support as compared to sitting in a regular office chair. Vigorous activity following periods of prolonged postures has been identified as a risk factor for low back pain (Adams and Dolan, 1996, McGill and Brown, 1992) due to the potential for hyperflexion injury (McGill and Brown, 1992, Parkinson et al., 2004) or ligament inflammation and alterations in muscular activation (Solomonow et al., 2003, Solomonow et al., 2004, Shin and Mirka, 2007). There are many occupations that involve prolonged sitting in a vehicle followed by high demand activities such as ambulance attendants, police officers and delivery truck drivers. Thus attention to the passive tissue response of prolonged seating in a vehicle is important to further understand injury mechanisms in these groups.

Gender differences in passive tissue viscoelastic creep have been identified in response to prolonged postures in vivo (McGill and Brown, 1996, Solomonow et al., 2003). Specifically, these authors found female participants demonstrated more creep but had a quicker recovery time than their male counterparts.

While some studies have investigated in-vivo lumbar spine stiffness in response to flexion (McGill and Brown, 1996, Parkinson et al., 2005, Solomonow et al., 2003, Shin and Mirka, 2007) only one has examined in-vivo passive lumbar spine stiffness specifically in response to prolonged sitting (Beach et al., 2005). As discussed previously, passive lumbar flexion moment-angle curves were generated before, during and at the end of a two hour trial of desk work while sitting in an office chair. The authors found that over the two hour period stiffness increased initially and then decreased in male subjects and was variable in female subjects.

From previous studies it has become apparent that gender differences are seat-type specific. Therefore, an investigation of passive lumbar spine stiffness in response to sitting in an automobile seat is important to further understand potential injury mechanisms in drivers and to provide additional information to aid in automobile seat design improvements.

2.14 Conclusion

From the literature presented in this paper it is apparent that prolonged driving is contributing to the costly condition of low back pain in our society. There is a clear link between increased in-vehicle exposure time and the development of low back pain. Studies conducted in both office chairs and automobile seats have found differences in lumbar spine and pelvic postures between genders. While these postural differences have been linked to differing passive lumbar spine responses in the office chair, currently the effect on passive structures during prolonged automobile sitting is unknown. Passive tissues, such as ligaments and intervertebral discs, have been clearly identified in the literature as sources of pain (Bogduk, 1983). If postural gender differences result in a different response from these tissues between men and women we may gain great insight into potential gender differences in injury mechanisms and pain generation pathways.

In summary, further investigation into the specific tissue response in men and women during sitting will lead to the development of better treatment and prevention strategies as well as assist in the optimal design of ergonomic office chairs and automobile seats.

Chapter 3 Methods

3.1 Participants

Twenty subjects (10 males and 10 females), with no history of low back pain within the past six months, were recruited from the university student population. Subjects were matched across gender for age and body mass index. The average age for males and females was 26.4 (+/- 3.47) and 25.2 (+/- 3.16) years respectively. Average body mass index (BMI) for males and females was 25.7 (+/-3.4) and 23.1 (+/-2.3) kg/m^2. All subjects signed an informed consent form prior to participation in the experiment. The experimental protocol was approved by the University of Waterloo's Research Ethics and Review Committee.

3.1.2 Recruitment of Participants

Participants were recruited using posters detailing the requirements of the study, which were approved by the Office of Research Ethics at the University of Waterloo. These were posted in the hallways and classrooms of Burt Matthews Hall.

3.1.3 Compensation

All subjects were compensated with a lab t-shirt for their participation.

3.1.4 Exclusion Criteria

Potential participants were excluded from the study if they had a history of severe back injury such as fracture or acute disc herniation, known spinal deformity or history of non-specific low back pain within the past six months.

3.2 Calibration of Equipment

The Xsensor3 seat pressure mapping system (Xsensor Technology Corporation, Calgary, AB, Canada) was calibrated once during pilot work. This calibration file was used for all testing sessions in this study. In order to determine the location of the center of pressure with respect to the chair throughout each collection period, one five second file calibration file was taken of constant digital pressure, provided by an assistant, maintained over the middle cell on the anterior edge of the seat pan and the middle cell on the right lateral edge of the seat pan. This calibration file was collected immediately before each participant arrived.

Two tri-axial accelerometers (S2-10G-MF, NexGen Ergonomics Inc., Montreal, Canada) were calibrated at the start of each collection, immediately before the participant arrived. To test for drift and loss of sensitivity due to the experimental conditions, the accelerometers were also recalibrated immediately at the end of each collection period.

3.3 Instrumentation

The subjects' skin was prepared with light shaving and rubbed with alcohol. Four pairs of Ag-AgCl pre-gelled disposable electrodes (Blue Sensor, Medicotest Incorporated, Ølstykke, Denmark) were affixed 20mm apart vertically, 2.5 cm bilateral to the spinous process of T9 and L3 over the erector muscle belly (McGill, 1991). A reference electrode was placed over the acromion process of the right scapula. EMG signals were band pass filtered (10-1000Hz) and differentially amplified with a common mode rejection ratio of 115 dB at 60Hz and input impedance of 10GΩ (model AMT-8; Bortec, Calgary, AB, Canada). The amplified EMG signal was then A/D converted with a sample rate of 2048Hz using a 12-bit +/-2.5V A/D conversion system.

During passive lumbar flexion trials, a force transducer (Transducer Techniques Inc., Temecula, CA, USA) was used in series with a cable to pull participants into flexion. Lumbar spine moments were calculated by the product of force recorded and the distance between the point of application of force and the estimated joint centre of L4/L5. A schematic of the passive lumbar flexion jig is shown in Figure 1.

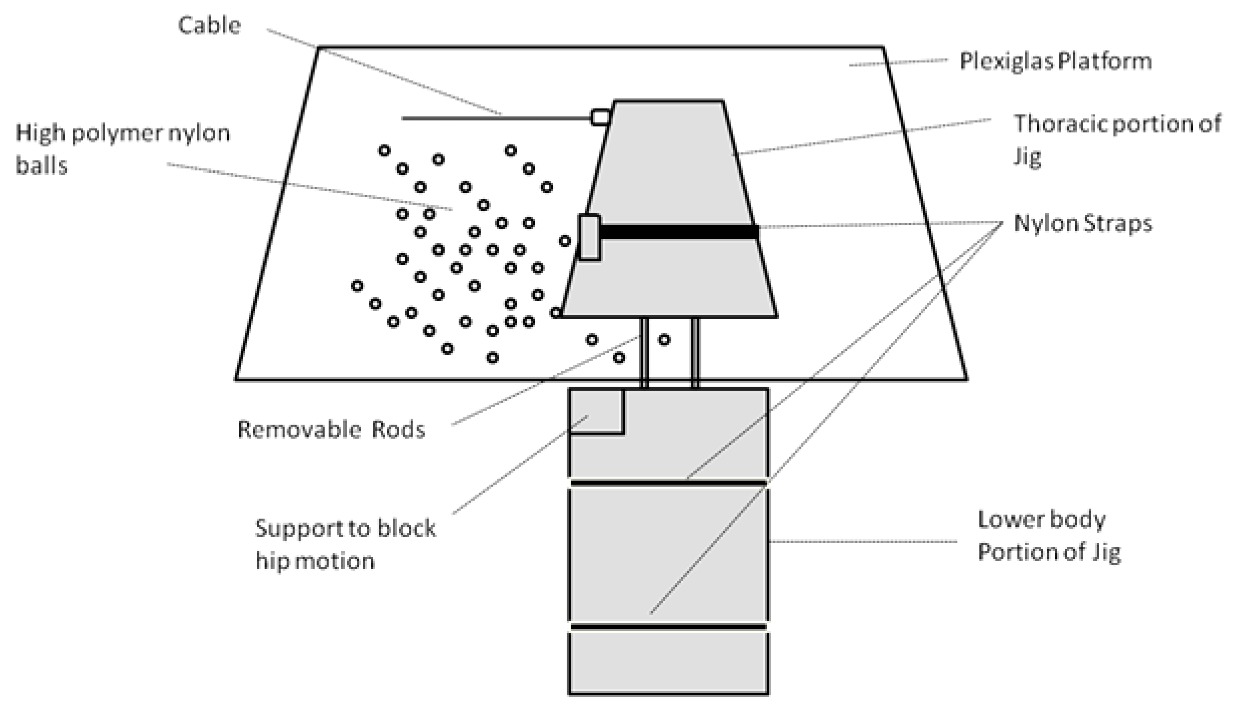

Figure 1: Schematic of Passive Lumbar Flexion Jig. Participants were positioned on their right side with iliac crests lined to the top of the hip support. The rods were removed once the participant was secured in the jig. Participants were pulled into flexion (counter-clockwise on the above diagram) by the cable.

A digital video camera (Panasonic, PV-DV202-K, Japan) was fixed to the ceiling perpendicularly over the passive range of motion jig. Reflective markers were attached to the point of application of force and the greater trochanter. A rigid fin with two reflective markers was constructed to fit over the L5 accelerometer. This fin was fixed to the subject during passive range of motion trials on the jig and then removed for the driving simulation trials. Interpolation of the line formed by these markers was used to estimate the joint center of L4/L5.

Two tri-axial accelerometers (S2-10G-MF, NexGen Ergonomics Inc., Montreal, Canada) were fixed over the spinous processes of L1 and L5 to provide a time-varying external measure of lumbar flexion angle and pelvic tilt during driving. In order to minimize movement during sitting the accelerometers were taped to the skin with the subject positioned in slight flexion. Accelerometer data was amplified (AMT-8, Watertown, MA) and sampled at a frequency of 2048Hz using a 12-bit +/-2.5V A/D conversion system.

The driving simulator consisted of an automobile seat, gaming steering wheel (Play Station TM, Sony 1998), pedals and modified dashboard (Figure 2). Participants drove around an oval course projected onto a screen in front of the dashboard (Grand Turismo 2, Polyphony, 1999). Subjects were given instructions to grip the steering wheel at the 10 and 2 o'clock positions and to maintain a speed of 100km/hr throughout the driving trials. In order to increase the realism of the driving trial, subjects were allowed to adjust the following parameters on the seat at the beginning of the experiment: seat distance from pedals, backrest angle, seat pan angle and seat pan height. These parameters were documented and then remained fixed for the remainder of the collection. Time varying seat pan and backrest pressure distributions were collected with a pressure mapping system fitted to the seat pan and backrest of the automobile seat (XSensor Technology Corporation, Calgary, AB, Canada).

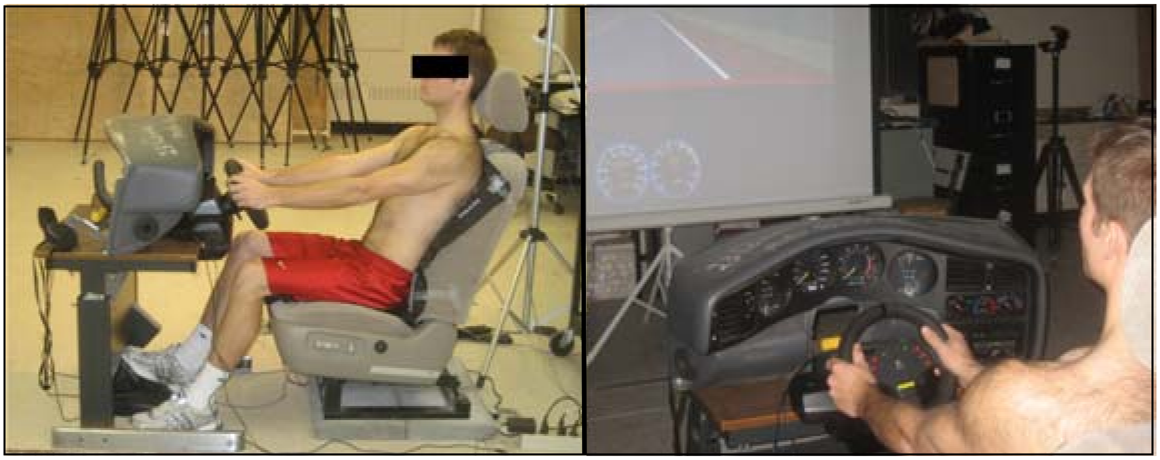
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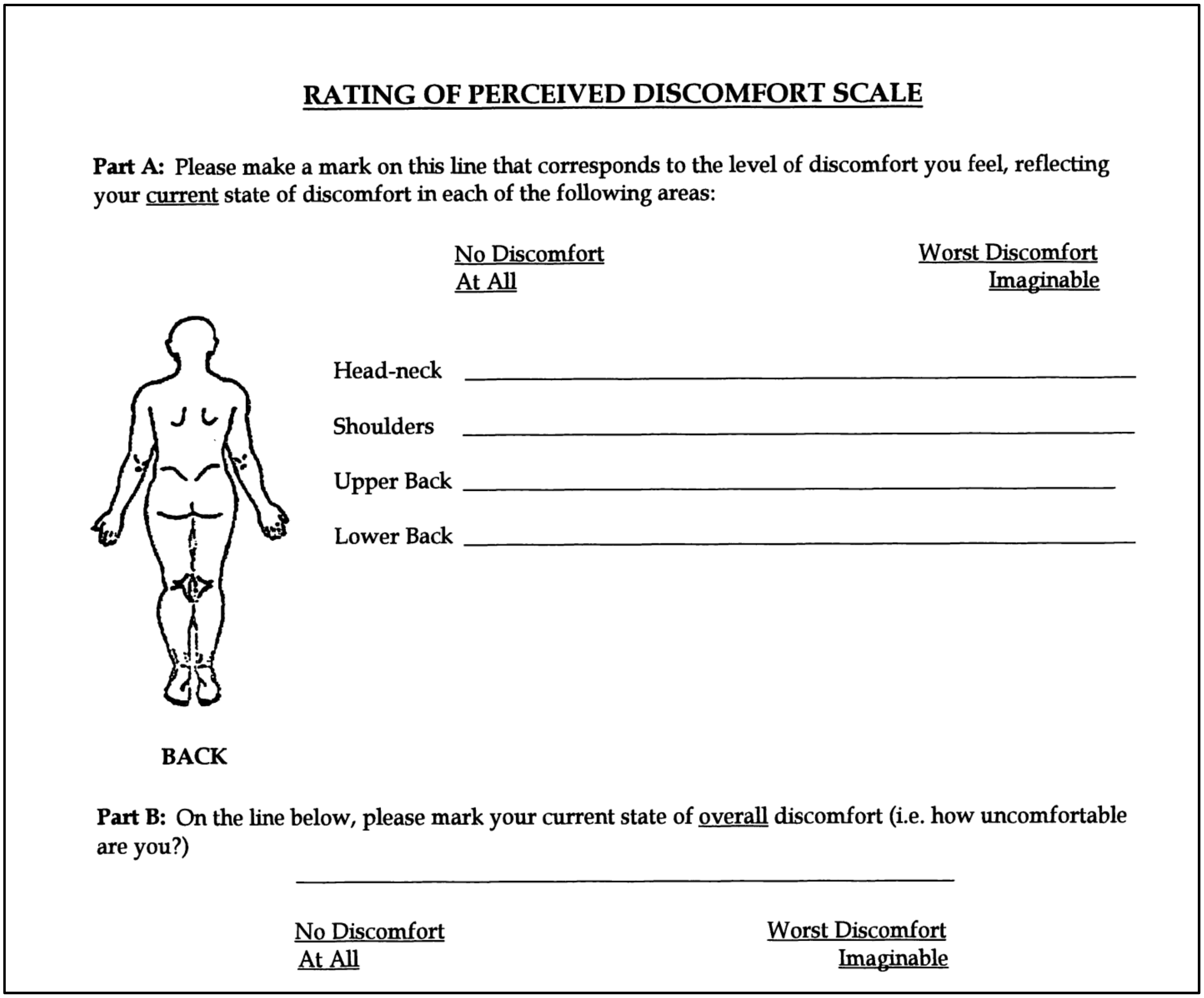
Figure 2: Driving simulator set up. Seat with pressure mapping system, pedals and steering wheel (Left), occupant's view of simulated road (Right).

Ratings of Perceived Discomfort using a 10 cm visual analogue scale (VAS) were taken at three points throughout the prolonged simulated driving trial: a baseline at the start of the experiment, after the first hour of simulated driving and after the second hour of simulated driving. Subjects rated four body regions including: head and neck, shoulders, upper back, lower back by indicating their discomfort with a line on a 10 cm VAS. An overall discomfort rating was also taken with the specific instructions “Please mark your current state of overall discomfort (i.e. How uncomfortable are you)” on a fifth 10 cm VAS (Figure 3).



RATING OF PERCEIVED DISCOMFORT SCALE

Part A: Please make a mark on this line that corresponds to the level of discomfort you feel, reflecting your current state of discomfort in each of the following areas:

No Discomfort At All — Worst Discomfort Imaginable

Head-neck ______________________________

Shoulders ______________________________

Upper Back ______________________________

Lower Back ______________________________

Part B: On the line below, please mark your current state of overall discomfort (i.e. how uncomfortable are you?)

____

No Discomfort At All — Worst Discomfort Imaginable

Figure 3: Rates of Perceived Discomfort Questionnaire.

3.4 Justification for the use of Accelerometers

Electronic devices such as inclinometers and uni-axial accelerometers have demonstrated greater approximations of radiographic measures (Adams et al., 1986); however, these instruments are limited by a significant amount of experimental error such as small ranges of measurement, steps in output angles, measurement about the orthogonal axis of the device and degradation of the signal as the inclination surpasses 60 degrees in either direction (Otun and Anderson, 1988).

In quasi-static situations such as quiet sitting, tri-axial accelerometers can be used as extremely sensitive tilt sensors that will output acceleration changes with respect to gravity in the principle axis. In the case of this study, the principle axis of the accelerometer was the y axis aligned vertically with positive y directed up, such that it will measure accelerations corresponding to flexion or extension about the transverse axis of the subject. Thus, accelerations in all three axes can be resolved and transformed into an angle with respect to the vertical without the limitations of inclinometers or uni-axial accelerometers which cannot be perfectly resolved due to the lack of a relative reference (Hansson et al., 2001). Using customized software, the lumbar flexion and pelvic tilt angles can be calculated (Figure 4).

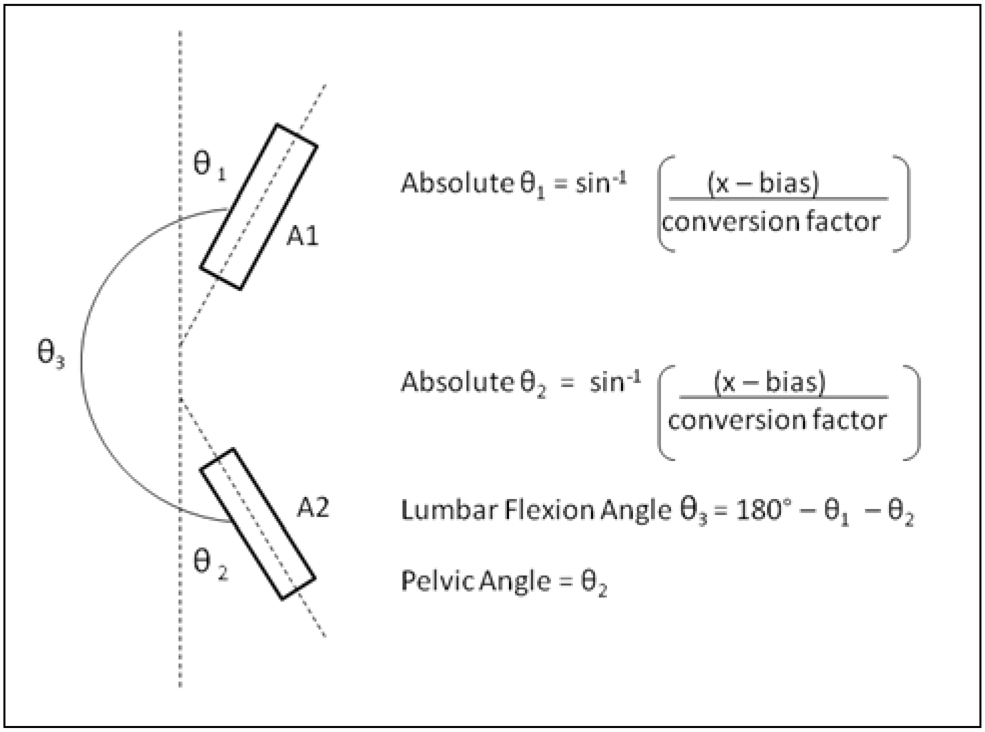


Figure 4: Method for determining Lumbar Flexion Angle and Pelvic Angle from accelerometers.

3.5 Data Collection

Each subject attended a four hour data collection. Before instrumentation, the participant was allowed to adjust the automobile seat as described in section 5.2. Figure 5 provides a schematic summary of the order of data collection.

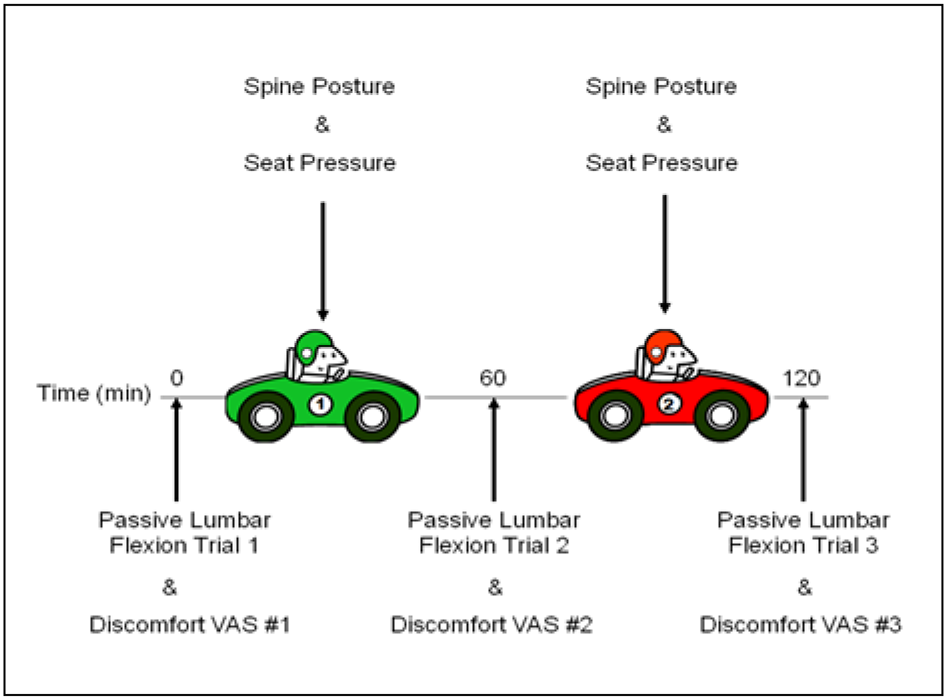


Figure 5: Order of data collection.

Data regarding the height, weight, and age of each participant was recorded at the beginning of each data collection. Anterioposterior trunk depth, at the level of the L4/5, was measured on each standing participant by the experimenter with a caliper ruler. This measure was recorded. The participant then completed a baseline perceived discomfort questionnaire in which they marked their discomfort in each of 4 body regions: head and neck, shoulder, upper back, lower back as well as overall discomfort.

Accelerometer data was amplified (AMT-8, Watertown, MA) and collected at a frequency of 2048Hz using the National Instruments Analog to Digital (NIAD) collection program (Department of Kinesiology, University of Waterloo, Waterloo, Ontario, Canada). Normalization trials were collected for the accelerometers. First, a 5 second quiet standing trial was collected with the subject standing looking straight ahead with feet shoulder width apart. Finally a 5 second full flexion trial was collected after the subject moved into full forward flexion, given the instructions to keep knees straight and pelvis level. This posture was maintained this position for 5 seconds to stabilize. During forward flexion, subjects were instructed to keep their knees straight. Following this procedure it was possible to normalize lumbar flexion within each subject for better comparison between participants.

EMG data, synchronized with the force and video data, were collected at a frequency of 2048Hz using the National Instruments Analog to Digital collection program. The EMG signal was differentially amplified (Model AMT-8, Bortec, Biomedical Limited, Calgary, Alberta, Canada). Maximum voluntary contractions were taken for the thoracic and lumbar extensor muscles by having the subject resist against external stabilization, provided by an assistant, in extension while lying prone on a bench (McGill, 1991).

The protocol used for obtaining passive lumbar spine range of motion has previously been described by Parkinson et al. (2004) and Beach et al. (2005). In brief, subjects were secured with nylon straps at the ankles, thighs, hips and rib cage on a near-frictionless jig lying on their right side. Knee angle was measured by goniometer and kept the same for each of the three trials. The lower portion of the jig effectively blocked any hip motion by means of a thick piece of wood that was aligned with the top of the iliac crest. The thoracic portion of the jig, capable of independent motion from the lower limb portion was secured at a standardized distance by rods and screws to ensure reproducible subject placement in the jig for each trial throughout the experiment. Once the subject was secured in the jig, the rods were removed.

The low friction surface of the jig is achieved by the use of nylon ball bearings (Salem Specialty Ball Incorporated, Canton, Connecticut, USA) between jig and table surface. A video camera (Panasonic, PV-DV202-K, Japan) was suspended to the ceiling perpendicularly directly over the jig. A LED trigger light was fixed within the field of view of the camera in order to link video data with force and EMG data. The subject was pulled into flexion by a cable with a force transducer (Transducer Techniques Inc., Temecula, CA, USA) in series until end range of motion was appreciated by the examiner and confirmed visually from the force transducer output (Figure 6). A metal rod was fixed to the point of application of force, parallel to the cable, to ensure that applied forces were as perpendicular to the thoracic jig harness as possible. Force data, collected at a sample frequency of 2048Hz using the NIAD collection program, was synchronized with the EMG signal. Passive trials were accepted if the EMG signal was less than 5% MVC. Average normalized EMG for the passive flexion trials was: 4.7 (+/-2.9) for the right thoracic erectors, 2.5 (+/-1.3) for the left thoracic erectors, 1.6 (+/-0.8) for the right lumbar erectors and 1.4 (+/-0.7) for the left lumbar erectors. Although EMG levels in the right thoracic erectors were approaching the 5% MVC level, in comparison to the remaining erector activity levels they were not considered to significantly contribute to the resistance of the applied flexion moment.

Lumbar flexion moment was calculated about the L4/L5 joint centre (Figures 6 and 8). Following three acceptable passive motion trials, the subject was removed from the jig and seated in the automobile seat and the first hour of simulated driving was initiated. During driving trials seat pressure data and accelerometer data were collected. For ease of collection and processing, trials were separated into fifteen minute blocks.


[redacted]

Figure 6: View of passive lumbar flexion measurement from video camera fixed to the ceiling directly over the participants. LED trigger light, used to synch coordinate data with EMG and force data, can be seen in the upper right hand corner of the image.

At the one hour mark the subjects completed a second discomfort questionnaire, and then were quickly transitioned to the passive range of motion jig where they were secured and tested. They were then returned to the car seat for the second hour of simulated driving. At the end of the second hour, a final discomfort questionnaire was completed and a final measure of passive range of motion was collected.

3.6 Data Reduction and Analysis

Data for one female subject was deemed unsatisfactory due to raw data file corruption. This subject was eliminated from the data analysis. Data for the remaining 19 subjects were analyzed using custom written software applications in both Visual Basic 6.0 Professional

Edition (Microsoft Corporation, Redmond, WA, USA) and MatLab 7.1 (The MathWorks Inc., Natick, MA, USA). Time varying accelerometer data were used to calculate the following: maximum lumbar flexion angle, average lumbar flexion angle, average pelvic angle with respect to the vertical and average pelvic angle with respect to upright standing for each frame of data. Seat pressure data was used to calculate: total pressure area of the seat pan and seat back, peak pressure area on the seat pan and seat back, center of pressure location on the seat pan and seat back. Discomfort data was extracted from the rates of perceived discomfort questionnaire and normalized to the first questionnaire responses. Specifically, the baseline VAS values in mm were subtracted from all three questionnaires (baseline, after 1 hour of sitting and after 2 hours of sitting) such that all baseline responses became zero. Data was then displayed in graphical format for visualization of general trends. Reflective markers were digitized from the video data for each passive lumbar flexion trial using the software package KinDig (Department of Kinesiology, University of Waterloo, Waterloo, Ontario, Canada) and then filtered with a dual pass Butterworth filter with a cut off frequency of 2.5Hz. Coordinate data were used to calculate the estimated joint centre of L4/L5 (by interpolating 43% of trunk depth from the posterior surface (McGill et al., 1988)), moment at L4/L5 and the normalized lumbar flexion angle for each trial (Figures 7, 8, 9).

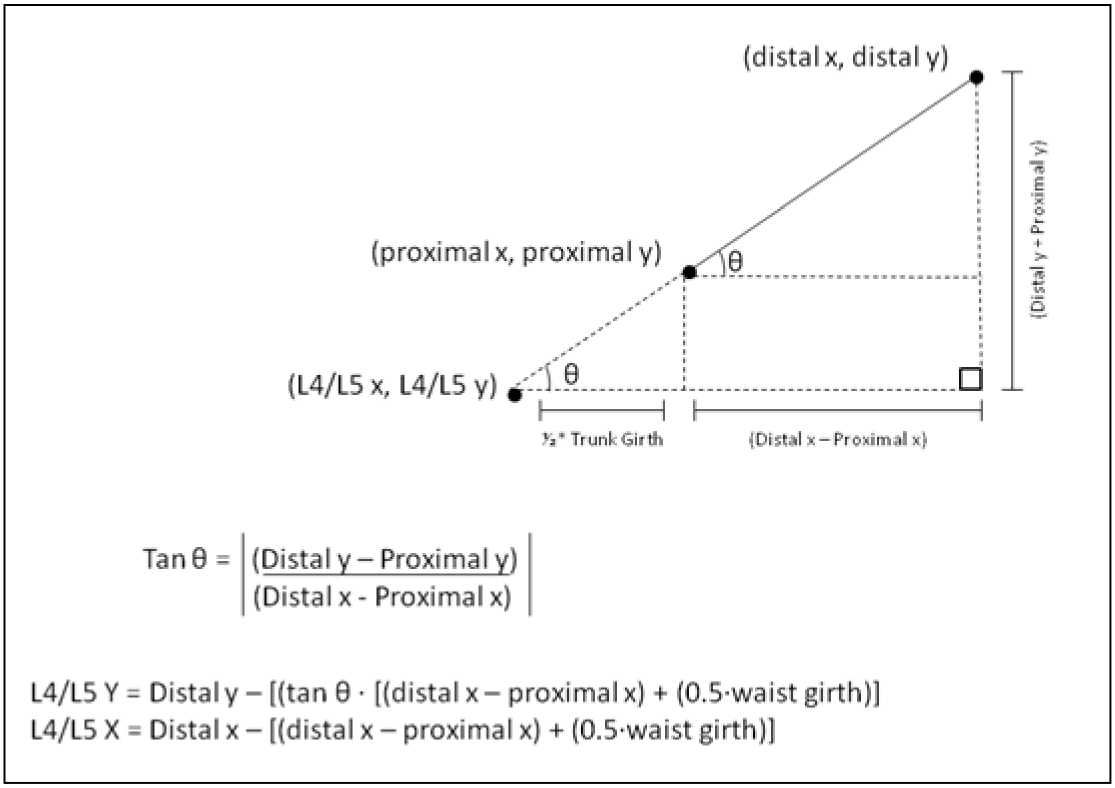


Figure 7: Method used determine estimated L4/L5 joint centre.

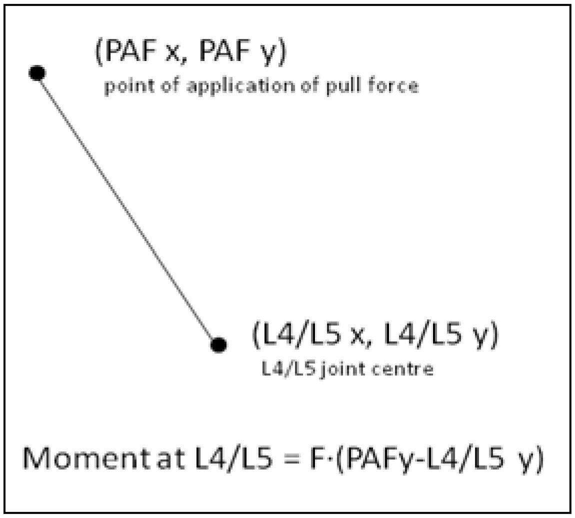


Figure 8: Method to determine passive moment at the L4/L5 joint centre.

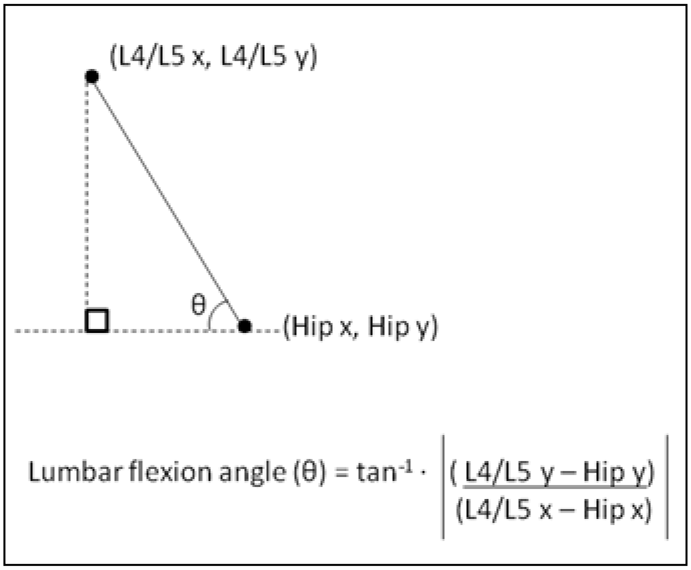


Figure 9: Method for determining the passive lumbar flexion angle on the range of motion jig.

To generate a measure of stiffness, passive moment-angle relationships were calculated from normalized lumbar angle data captured by video and the cable tension needed to pull subjects into flexion while side-lying on the low friction table. Specifically, the filtered force data was multiplied by the perpendicular distance measured between the cable attachment and the estimated joint centre of L4/L5 producing the extensor reaction moment (Figure 8). Lumbar flexion angles were normalized to the maximum flexion angle measured in trial 1 in order to facilitate comparison between subjects. Passive moments at L4/L5 were plotted against normalized lumbar flexion angles to produce stiffness curves (see figure 10).

To interpret these stiffness curves, analysis protocols presented by Beach et al. (2005) were used. Essentially, each stiffness curve was divided into three sections: low, transition and high zones by low and high "breakpoints" (represented by dashed lines on figure 10). To determine breakpoints, each curve was fit with 5th order polynomials (average r^2=0.98, +/- 0.005). These curves were then differentiated in order to identify the points of greatest change in slope: the breakpoints. Using original data, the slope of each of these zones was calculated to give a measure of passive flexion stiffness. Attention was also given to the breakpoint values across each of the three trials. Shifting of these breakpoints to the right or left was interpreted as a decrease or increase in stiffness respectively. Thus, for each trial values of maximum normalized flexion angle, transition zone slope and moment-angle curve breakpoints were analyzed.

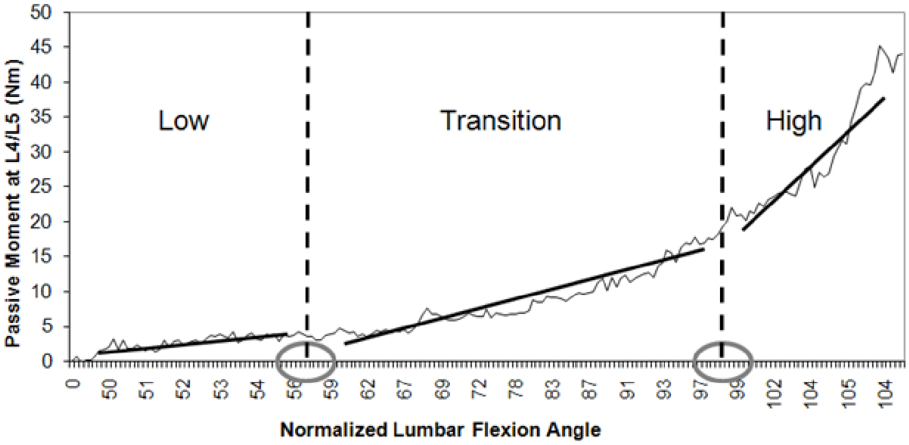


Figure 10: Passive Flexion stiffness curve for one participant (trial 3a). Dashed lines separate low, transition and high zones. Circles represent the breakpoint values. Solid lines represent slopes for each region superimposed over raw data.

3.7 Statistics

Two-way analyses of variance (general linear model), with time as the within factor and gender as the between factor, were completed to compare dependent variables during passive flexion and simulated driving trials. A one-way analysis of variance (general linear model) (ANOVA) was then completed on the dependent variables maximum lumbar flexion and average lumbar flexion during prolonged sitting for the female participants to determine significant changes in lumbar posture with respect to time. Post hoc tests were completed when significant interactions were found using the least significant difference method. In all statistical tests a p-value of less than 0.05 was accepted as statistically significant.

Chapter 4 Results

4.1 Summary of Results

Gender differences were found in the passive lumbar stiffness and time varying lumbar spine posture throughout this study. Seat pressure variables were similar for male and female participants with increases found in total area, peak pressure and total pressure throughout the two hour simulated driving trial. Ratings of Perceived "Overall" Discomfort increased steadily over time for all participants, with female subjects reporting higher levels of discomfort. Discomfort ratings specific to the lumbar region of the back increased over time for all participants after the first hour of driving but decreased in female participants during the second hour as opposed to continuing to increase as reported by males.

4.2 Passive Lumbar Spine Stiffness

4.2.1 Low, Transition and High Zone Slope

Table 1 presents a complete summary of zone slopes calculated from the stiffness curves throughout the experiment. Essentially, the three zones reflect stiffness in each of the initial, mid and end range of lumbar motion in flexion. Therefore, stiffness changes in the low and transitional ranges of lumbar flexion would have the greatest functional impact as these are the ranges of motion that most people use in everyday activities.

Table 1: Average low, transition and high zone slopes and their standard deviations for all three passive lumbar flexion trials. No significant gender differences were found. Trends indicate that passive lumbar stiffness in the transition zone increased over time for male participants and increased and then decreased for female participants .

		Males		Females	
		Slope (NM/Normalized Flexion Angle)	SD	Slope (NM/Normalized Flexion Angle)	SD
Before Driving Trial	Low	**0.53**	0.15	**0.38**	**0.25**
	Transition	**0.80**	0.19	**0.54**	**0.14**
	High	**1.86**	0.64	**2.21**	**1.89**
After 1 hour of Simulated Driving	Low	**0.48**	0.21	**0.45**	**0.46**
	Transition	**0.86**	0.31	**0.83**	**0.87**
	High	**2.98**	1.70	**2.93**	**3.06**
After 2 hours of simulated driving.	Low	**0.54**	0.19	**0.30**	**0.12**
	Transition	**0.94**	0.31	**0.57**	**0.19**
	High	**2.36**	1.35	**1.68**	**1.05**

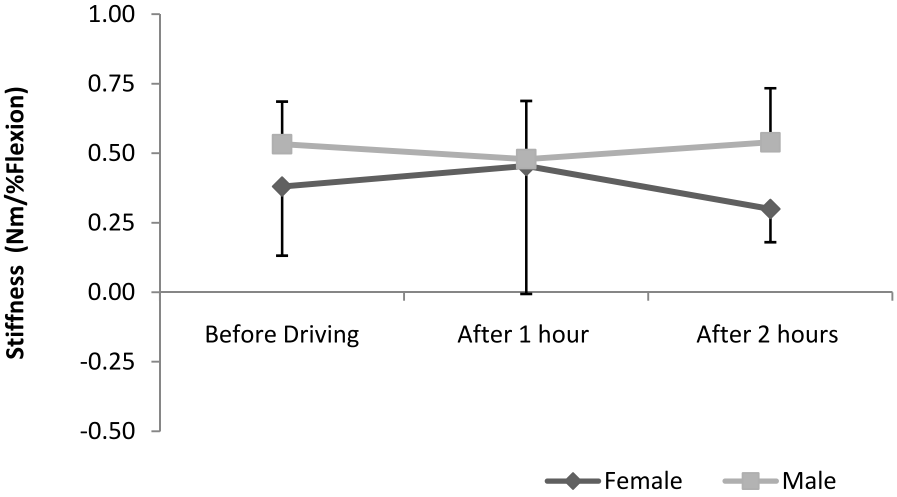


Figure 11: Average low zone stiffness for men and women. No significant differences were found in low zone stiffness between genders. Low zone stiffness remained essentially unchanged across the two hours of simulated driving.

Also, low zone stiffness remained generally unchanged across trials for both men and women (Figure 11). Transition zone stiffness in males tended to increase steadily across all trials while average results for female subjects suggest an initial increase after trial two and then decreased in stiffness after trial three (Figure 12).

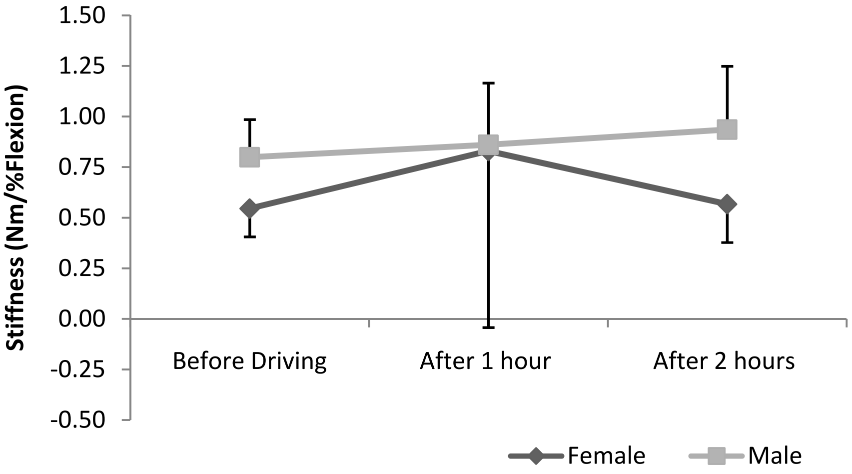


Figure 12: Average transition zone stiffness for men and women across 2 hours of simulated driving.

Slopes were essentially the same for both males and females in the high zone with both genders displaying an initial increase in stiffness after trial two and then a decrease in stiffness after trial three (Figure 13). When data from men and women were combined, the high zone slope measured during the second trial was significantly different from trials one and three (p=0.0171). While no significant gender-by-time interactions were found, trends suggest that females displayed a greater decrease in stiffness in high zone stiffness than males after trial three.

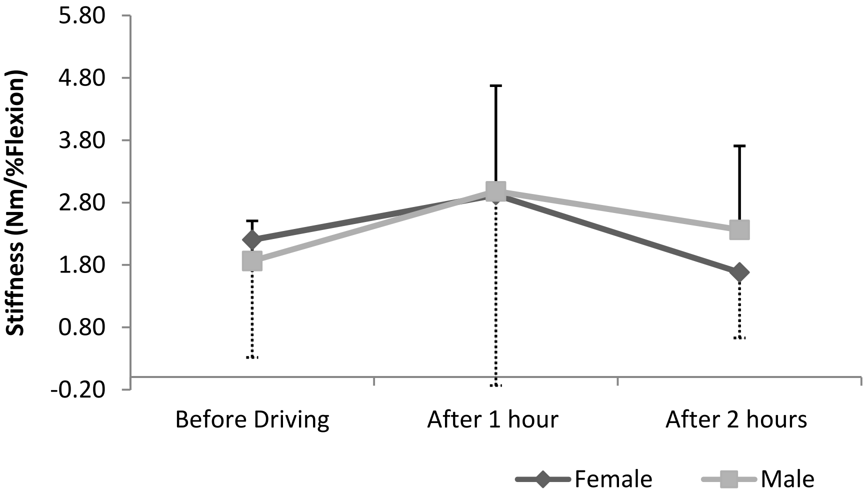


Figure 13: Average high zone stiffness for men and women across 2 hours of simulated driving.

4.2.2 Moment-Angle Curve Breakpoints

Curve breakpoint results are presented in figures 14 and 15. No significant differences were found between men and women for high and low curve breakpoints over time. Trends indicated a right shift in both low and high break points for women between trial 1 and trial 2 whereas little change was found in breakpoints over time for men.

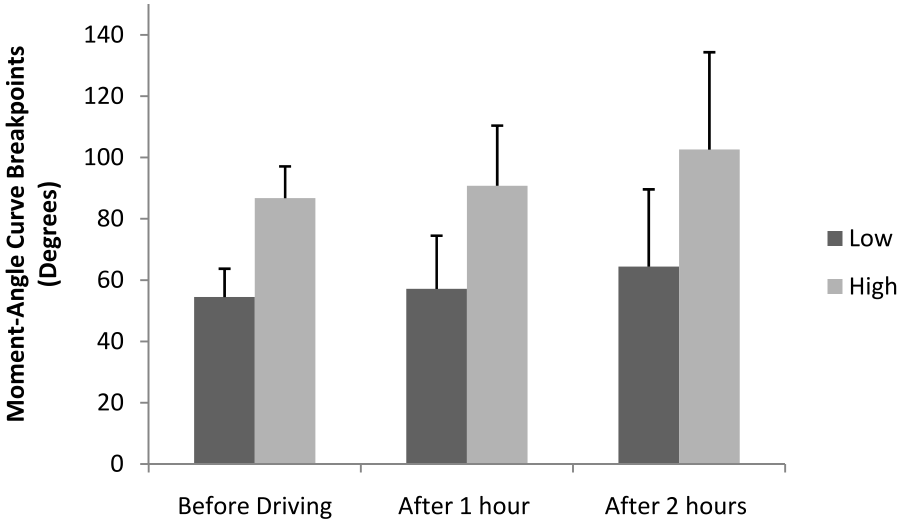


Figure 14: Average low and high female breakpoints for all three passive lumbar flexion trials. No significant differences were found in breakpoints over time between genders. Trends suggest a slight right shift in female breakpoints.

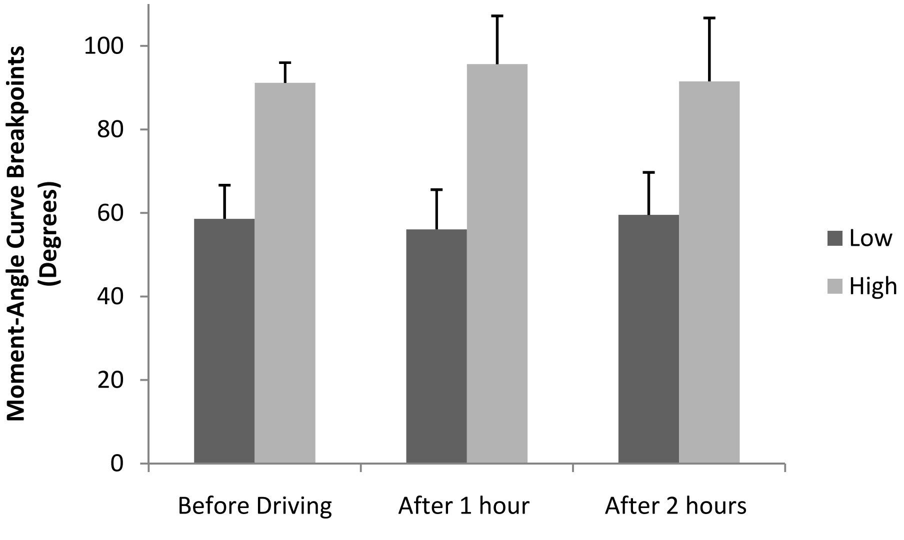


Figure 15: Average low and high male breakpoints for all three passive lumbar flexion trials. Breakpoints remained essentially the same throughout the experiment.

4.2.3 Maximum Lumbar Flexion Angles

No significant differences between men and women were found between maximum lumbar flexion angles adopted during driving. Figure 16 illustrates that on average males and females responded very similarly across the first hour of simulated driving with little change in maximum flexion angle at Trial 2, however, non-significant increase in maximum flexion angle was found for females after trial 3 with a slight decrease in maximum flexion angle for males.

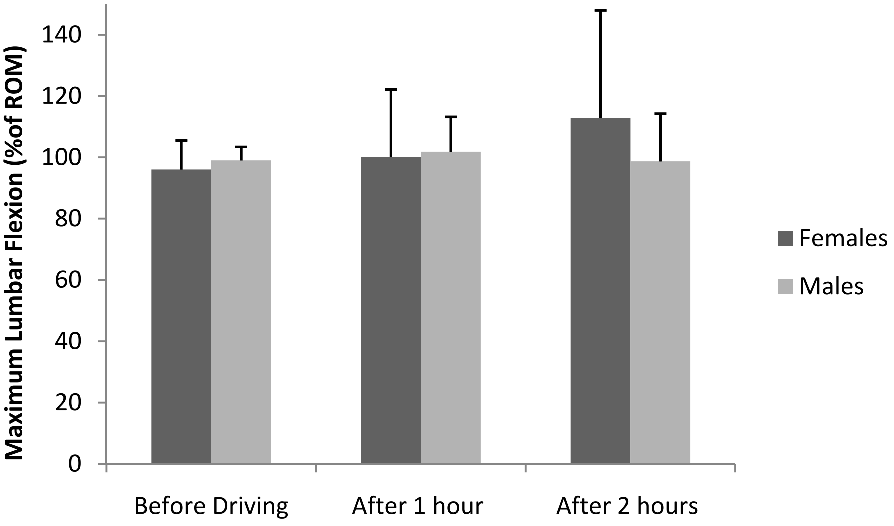
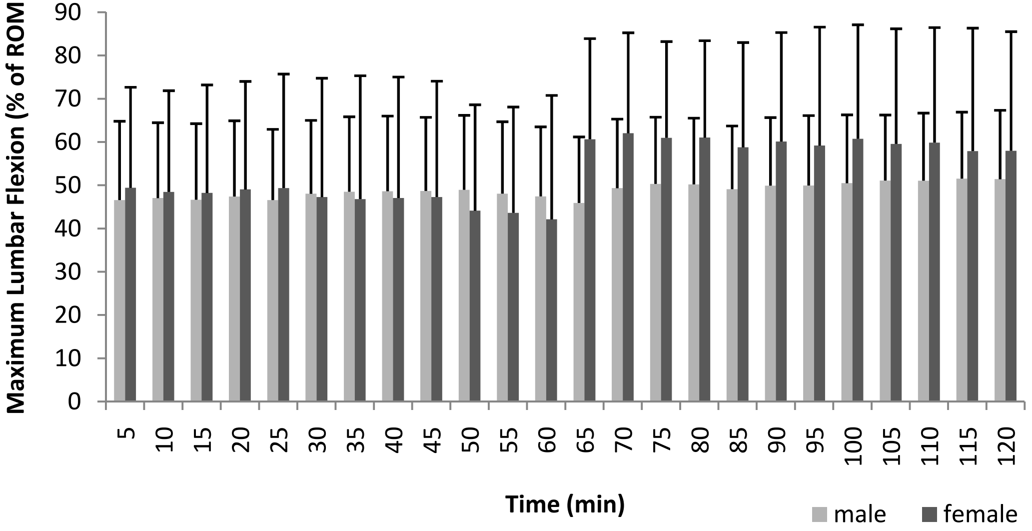


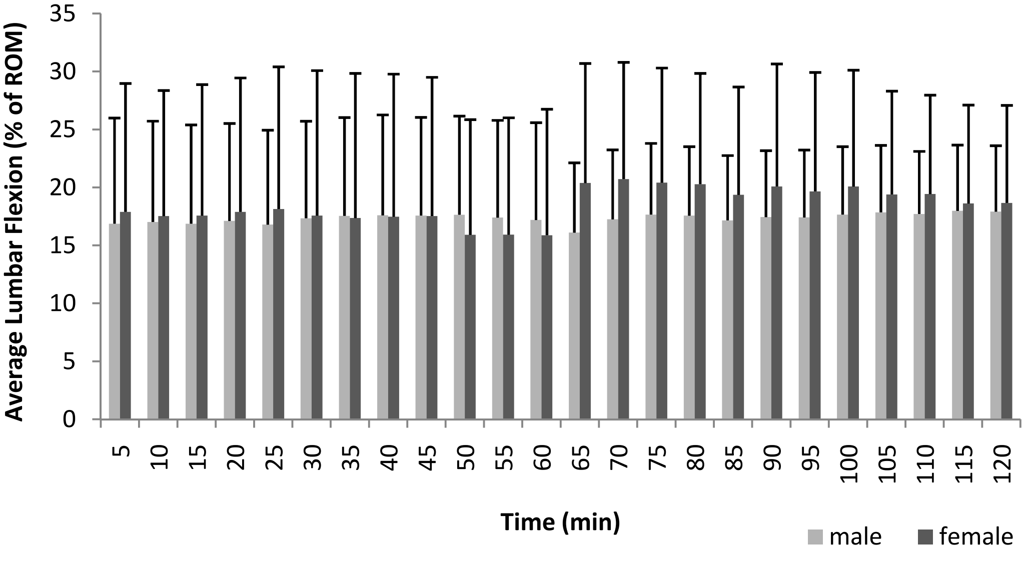
Figure 16: Maximum normalized lumbar flexion angles averaged for male and female subjects across all three trials. No significant differences were found between genders for maximum normalized lumbar flexion angles. Trends suggest that female subjects on average experienced a slight increased in lumbar range of motion across the three hours of simulated driving.

4.5 Sitting Posture

Figure 17 illustrates the time-varying lumbar spine posture for men and women during prolonged simulated driving trials. A significant interaction between gender and time was found for both time-varying maximum lumbar flexion angles and average lumbar flexion angles during the prolonged simulated driving trials (maximum lumbar flexion p=0.005 and average lumbar flexion: gender*time p=0.0458. Specifically, females were found to have significantly greater maximum lumbar flexion on average with 53.4 degrees (SD 6.9) compared to men with 48.9 degrees (SD 1.7) and significantly greater average lumbar flexion with 18.5 degrees (SD 1.5) compared to men with 17.4 degrees (SD 0.4).



(a)



(b)

Figure17: Time-varying average (a) and maximum (b) lumbar flexion angles in degrees measured by accelerometers during simulated prolonged driving trials for males and females.

Males did not significantly alter their time-varying maximum or average lumbar flexion posture during both driving trials. However, when female posture data were analyzed separately from male data, both average lumbar flexion angles and maximum lumbar flexion angles in female subjects were found to change significantly over time ($p=0.0008$ and $p<0.0001$ respectively). Specifically, these changes appear to occur in approximately 20 minute time blocks (figure 18 a, b). With respect to time-varying average lumbar spine angle, posture during the 45-60 minute period was significantly different from postures during 65-100 minutes and posture during 65-80 minutes was significantly different the first 40 minutes of sitting ($p=0.0387$). With respect to time-varying maximum lumbar spine angles, postures during minutes 25-40 were significantly from postures measured during 65-100 minutes, postures during 45-60 minutes were significantly different from the second hour of sitting and postures during 65-80 minutes were significantly different from the first hour of sitting ($p=0.0170$). Both maximum and average time-varying lumbar flexion angles showed a decreasing trend in both women and men within each hour of simulated driving.

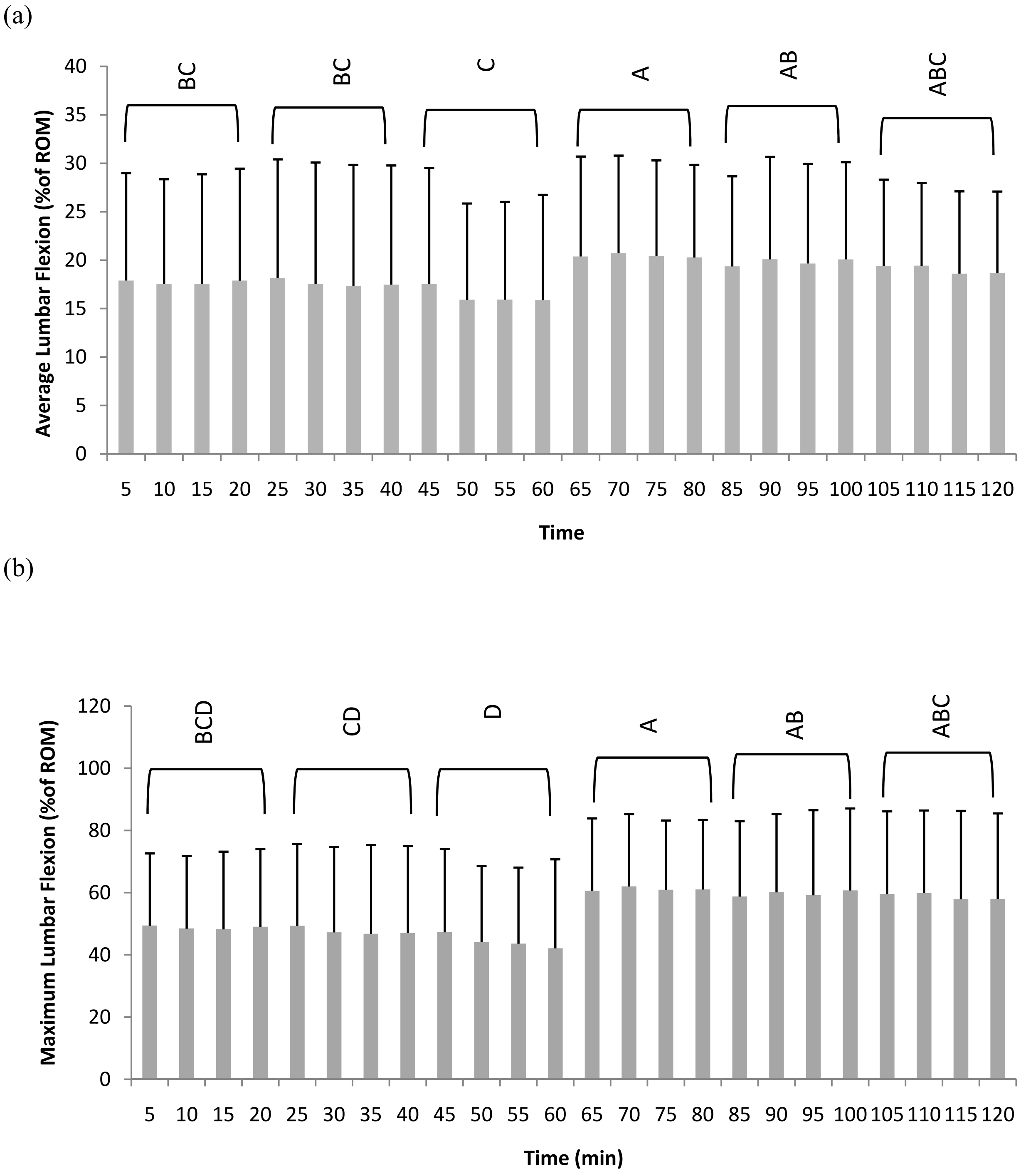
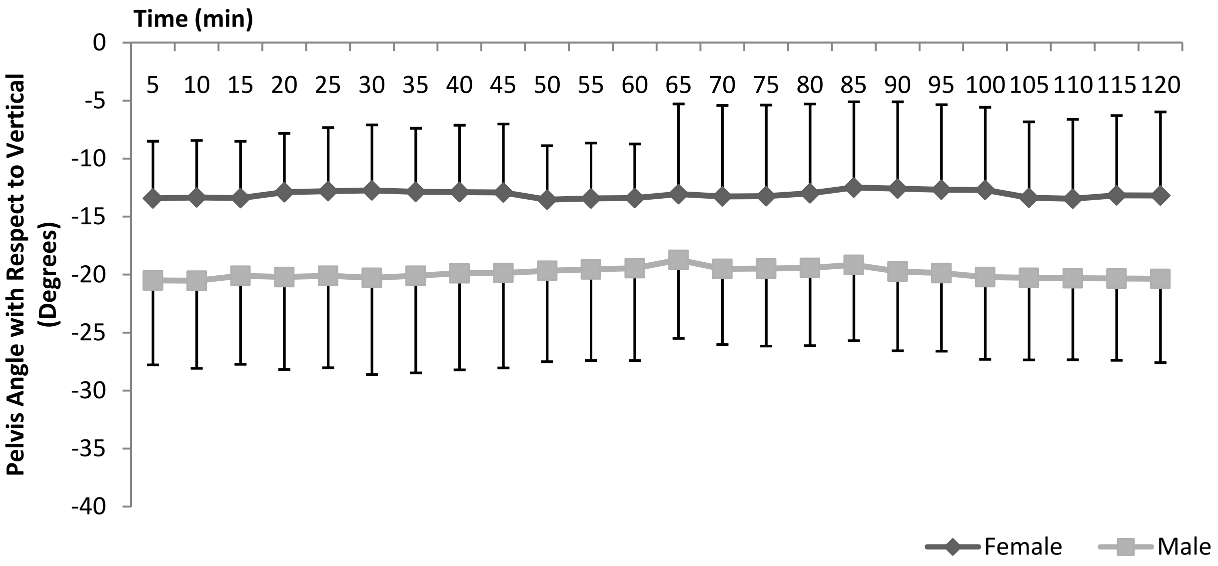


Figure 18: Time-varying maximum (a) and average (b) lumbar angles for females during the prolonged simulated driving trials. Women changed their posture significantly over time for both measures. Visually, these changes appear to occur approximately every 20 minutes. Statistically, 20 minute time blocks were found to be significantly different as outlined on each figure. Time blocks with the same letter were not significantly different from each other. For both average and maximum measures, the last time block of the first hour was signficantly different from the first block of the second hour.

Pelvic angles, both with respect to the vertical and with respect to upright standing, were not statistically different between men and women. Average values of -19.9º (SD 0.46) for men and -13.08º (SD 0.32) for females were found for time varying pelvic angle with respect to the vertical and average values of -30.0 (SD 0.45) and -29.0º (SD 0.32) were found for time varying pelvic angle with respect to upright standing (figure 19). The negative values indicate posterior rotation of the pelvis. These postures were fairly static throughout both hours of simulated driving trials. Unlike lumbar spine posture, there were no abrupt changes in pelvic posture for women at the start of the second hour of driving.

(a)



(b)

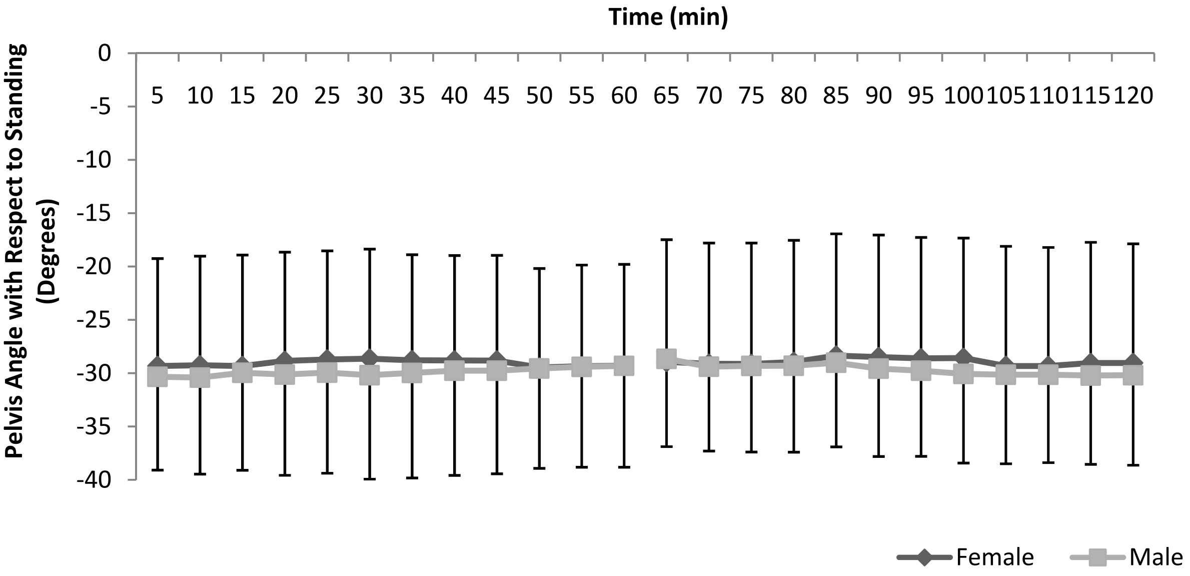


Figure 19: Time-varying pelvic posture (a) with respect to vertical and (b) with respect to upright standing for both males and females measured by tri-axial accelerometers during prolonged simulated driving trials. No significant pelvic posture differences were found between genders

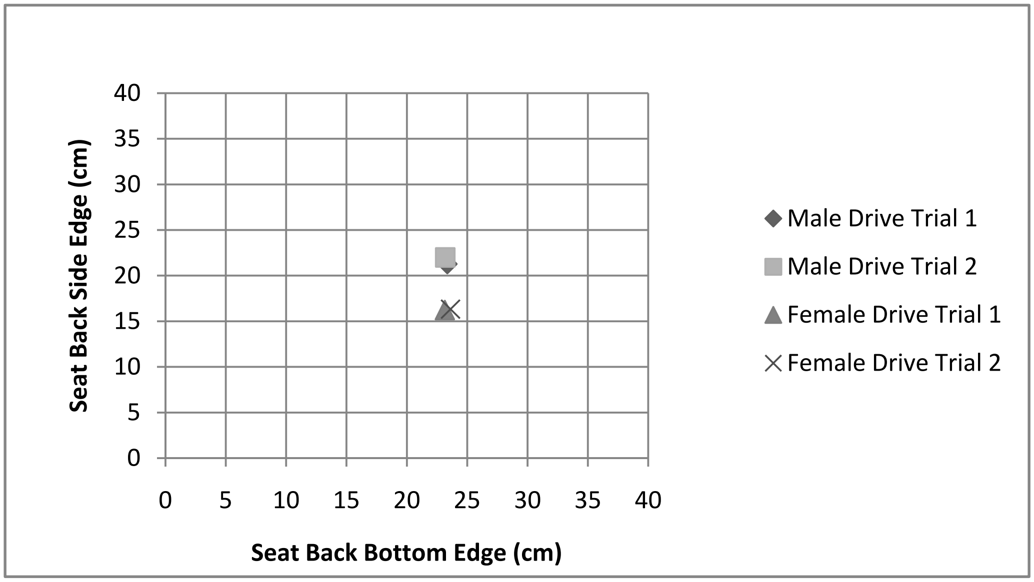
4.6 Seat Pressure

Due to loss of data caused by equipment failure, seat pressure data were only analyzed for 7 male and 6 female subjects. No significant gender differences in sitting pressure area were found. Significant increases over time were seen in total pressure area for both the seat pan 1314.7cm^2 to 1346.0 cm^2(p=0.0086) and seat back 486.09 cm^2 to 521.29 cm^2 (p=0.0248) (Table 2). Peak and total seat pan pressure increased significantly over time for all subjects (p<0.0129 and p<0.0005 respectively). Center of pressure movements on both the seat pan and seat back were considered negligible across the three hours of simulated driving for both male and female participants (Figure 20).

Table 2: Average automobile seat pressure results for all subjects during both simulated driving trials.

	Drive Trial 1				**Drive Trial 2**			
	Seat Pan	**SD**	**Seat Back**	**SD**	**Seat Pan**	**SD**	**Seat Back**	**SD**
Total Area (cm^2)	1314.7	231.0	486.1	88.8	1346.0	252.4	521.3	96.4
Total Pressure (mmHg)	30140.2	2592.0	7397.2	1769.2	31893.0	2916.3	7879.9	1862.6
Peak Pressure (mmHg)	135.4	1.0	122.6	6.4	152.3	15.5	137.0	3.0

(a)



(b)

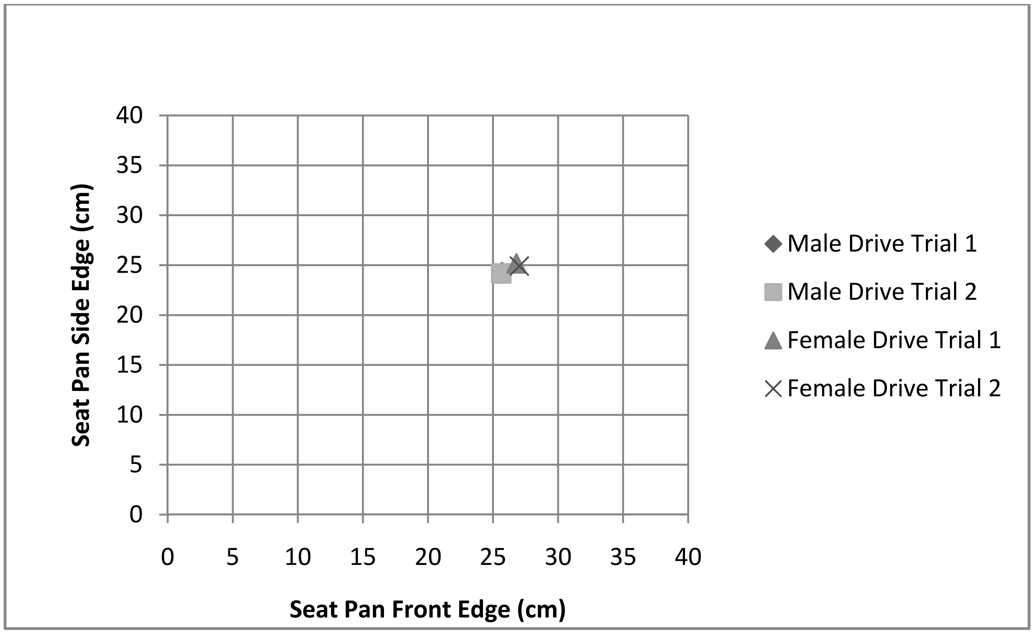


Figure 20: Average center of pressure locations on (a) seat pan and (b) seat back measured by the pressure mapping system during both simulated driving trials.

4.7 Discomfort

Figure 21 illustrates that the average normalized perceived discomfort ratings for "overall discomfort" collected during the experiment increased steadily across time, with females reporting greater discomfort than males. Figure 22, shows average normalized perceived discomfort ratings for the low back region specifically. Males show a slight increase in discomfort, whereas females demonstrate a large increase in discomfort followed by a slight decrease in discomfort at the end of the second hour of driving.

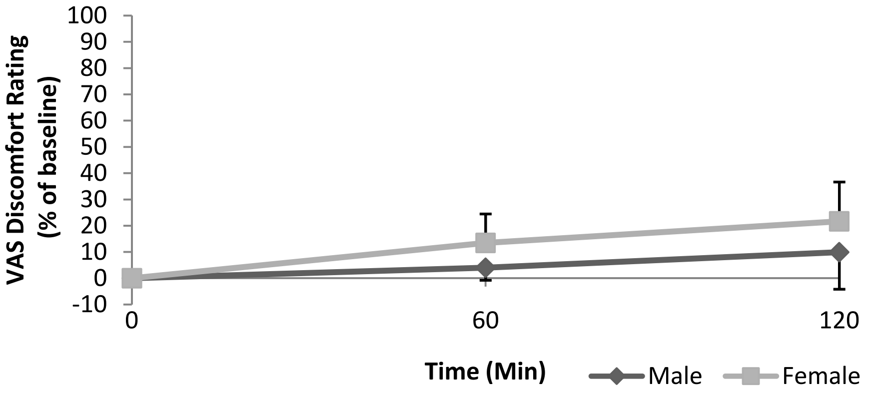


Figure 21: Normalized rates of perceived "overall" discomfort measured by visual analogue scale at three points throughout the experiment. Discomfort increases across time, with females reporting higher levels of discomfort than males.

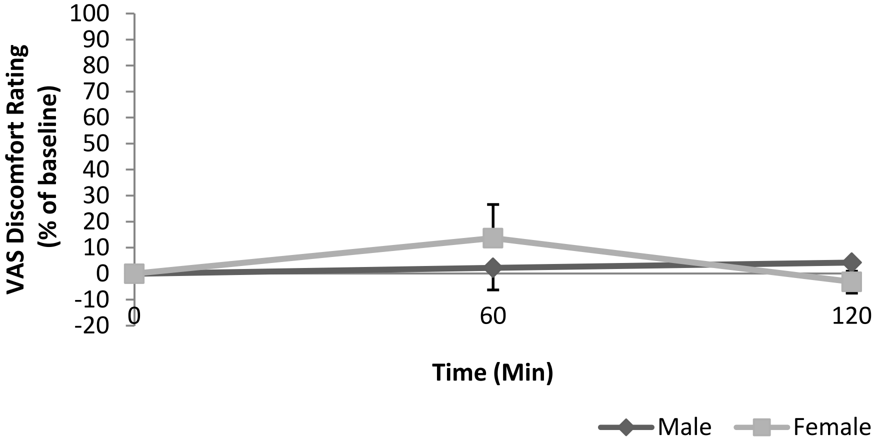


Figure 22: Normalized rates of perceived "low back" discomfort measured by visual analogue scale at three points throughout the experiment. Discomfort increases across time slightly for males, while females report and initial increase in discomfort followed by a slight decrease in discomfort at the end of the second hour of driving.

Chapter 5 Discussion

The results of this study suggest that time-varying changes in lumbar spine stiffness exist in response to prolonged simulated driving. On average, moderate increases in passive lumbar spine transitional zone stiffness were found initially in both males and females after one hour of sitting. While this modest increase in stiffness continued throughout the second hour for men, it was found to decrease slightly by the end of the second hour in females. In addition, a right-shift in break points as well as increasing maximum lumbar flexion trends were observed in female subjects.

These results suggest that at the end of the driving trials males were marginally stiffer than their initial measurements while female subjects exhibited a slight decrease in stiffness and for the most part were found to exceed their initial range of motion measurements. Although modest, these gender differences in stiffness prompt the suggestion that there may be a gender specific response to passive tissue strain at the cellular level.

These responses are quite different than those presented by Beach et al. (2005). In their data male stiffness increased initially and then decreased by the end of the second hour of sitting and female results were variable. In this study, while female results did have greater variation than male data, in this study it a trend of decreasing stiffness in female subjects was apparent. In fact, the average female stiffness response in this study showed similarities to the male data presented by Beach et al. (2005). In that study, time-varying postural data found a larger lumbar flexion angle in males as opposed to females. This suggests that just as male occupants tend to adopt a more flexed lumbar posture in an office chair, females tend to adopt a more flexed lumbar posture in automobile seats. Thus, this prolonged increase in lumbar flexion could be responsible for the passive lumbar stiffness response found in both studies. While it seems that in the office chair, men prefer to sit with a rounded back, preference may not be the reason behind female posture in an automobile seat. It is known from previous literature that females tend to adopt a more upright posture in an office chair (Dunk et al., 2005); therefore, the increase in lumbar flexion while sitting in a car seat might be due to lack of low back support from the automobile seat. In both this study and the work of Beach et al. (2005), increased lumbar spine flexion was associated with a decrease in passive lumbar spine stiffness, a condition that has been highlighted in the literature as a potential for a variety of injury mechanisms (Adams and Dolan, 1996, McGill and Brown, 1992, Parkinson et al., 2004, Solomonow et al., 2003, Solomonow et al., 2004, Shin and Mirka, 2007). This data also appears to agree well with past gender differences in passive tissue viscoelastic creep during prolonged extreme flexed postures in vivo (McGill and Brown, 1996, Solomonow et al., 2003) where female participants demonstrated more creep and a quicker recovery time than their male counterparts.

These gender differences in response seem to complement the lumbar spine and pelvic posture data that were recorded throughout the two hour simulated driving trials. On average, male subjects sat with fairly static lumbar angles while female subjects, as hypothesized, sat with greater lumbar flexion than men. Both male and female subjects had similar pelvic angles that remained unvarying throughout the driving simulation which was not expected. In previous studies, female subjects were found to have relatively greater posterior pelvic rotation compared to men (Coke et al., 2007). This lack of pelvic movement is most likely due to the constraints imposed by the car seat.

The spine and pelvic posture results from this study generally agree well with those noted previously for automobile seat sitting (Coke et al., 2007). Similar to the findings of Beach et al. (2005) postural and stiffness changes did not begin to emerge from the data set before 40 minutes of sitting. This further emphasizes the importance of increased study duration for sitting tasks as well as increasing the relevance to everyday life. An interesting observation from these results is the time-varying changes in female lumbar spine postures, especially at the start of the second hour of simulated driving, while very little alteration is observed in the male participants. It has been suggested previously that the constraints imposed by the automobile seat (foam bolsters, pedals, steering wheel and line of sight) minimize the postures that can be adopted by occupants (Jones, 1969, Preuschen and Dupuis, 1969). Therefore, it is likely that during the first hour of simulated driving changes at the level of the passive tissues were occurring in female subjects, but they were unable to grossly alter their posture due to the constraints of the seat. Once they were able to get up for the second passive range of motion trial and then sit back down again they were able to select a "new" posture at the start of the second hour of simulated driving. Examining the female lumbar posture data, it appears that female participants were attempting to modify their postures due to increased discomfort. Indeed, overall and low back discomfort rated by females increased after the first hour of simulated driving. This gross change in lumbar posture might have helped female participants deal with discomfort in the lumbar spine region as female ratings of discomfort for this region decreased after the second hour. While time-varying erector spinae muscle activity was not analyzed in this study, it is possible that female participants were experiencing discomfort from muscular fatigue. In this hypothetical situation an increase in lumbar spine flexion would provide relieve by transferring the erector moment to the posterior passive elements of the lumbar spine.

The remarkably static pelvic angles that were measured for both genders are reflective of the posture constraint imparted by the automobile seat. Unlike the lumbar posture data, there were no abrupt changes in pelvic posture for the female subjects when they sat down for the second hour of simulated driving. This further reinforces that pelvic postures are seat dependent and the only real change in posture when sitting in an automobile seat must occur in the lumbar spine. If the pelvis is fixed and lumbar flexion is increased for a prolonged period of time, it is reasonable to assume that this posture will result in some degree of viscoelastic creep in the pelvic and lower lumbar ligaments which would result in decreased lumbar spine stiffness. Since females were shown to sit with the same pelvic posture but with greater lumbar flexion compared to men, it is not surprising that they also demonstrated decreased passive flexion stiffness in the passive moment-angle trials throughout the course of the study.

Time-varying seat pressure data reflects the pelvic posture findings. Very little pelvic movement was recorded and likewise, very little movement of the seat pan centre of pressure was measured. Coke et al. (2007) reported significant movements of both seat pan and seat back CoP during a 1 hour trial of simulated driving. The increase in total seat area (both seat pan and backrest) matches with the results previously found that occupants tend to sink into automobile seats over time (Sember, 1994, Coke et al., 2007). However, instead of a decrease in peak pressure over time as previously noted by other researchers, the results in this study show a significant increase in peak pressure. Since seat pressure is closely linked with the foam used on the chair, the chair used in this study might have been older than those used previously. Depending on what point the seat foam "bottoms out" during the trial, it would be reasonable to slowly see an increase in total pressure area and peak pressure over time if this occurred at some point in the study. From the results presented in this study it is likely that bottoming out of the seat pan foam indeed occurred. This would support the lack of movement of the seat pan and seat back COP as well as the comparatively larger measures for total pressure, peak pressure and total pressure area compared to earlier literature (Coke et al., 2007). Future studies should include a measure of foam deformation over time when analyzing time-varying changes in seat pressure distributions.

Beach et al. (2008) investigated the correlation between hip and low back flexibility to lumbar and pelvic postures in the office chair and automobile seat. While not statistically significant, females were found to generally exhibit greater hip and low back flexibility compared to males and tended to sit with greater lumbar flexion during simulated driving. In automobile seats, participants with greater hip flexibility sat with statistically significant greater lumbar flexion. The authors suggested that flexibility may play a large role in the postural gender differences previously seen (Dunk and Callaghan, 2005, Gregory et al., 2006, Coke et al., 2007). While hip flexibility was not a factor studied in this experiment, it is possible that the female participants had greater hip flexibility than males, thus allowing greater lumbar spine flexion during sitting. However, hip motion was blocked by the passive flexion jig harness thus increased flexibility would not have affected lumbar stiffness measurements. Likewise, there was little difference between pelvic postures between genders or over time, which makes hamstring flexibility a less likely factor in these results. Also, the results of the time-varying lumbar posture data and passive lumbar flexion data strongly agree, so it is likely that factors other than initial lumbar and hip flexibility alone resulted in the stiffness responses seen in this study.

Increased seat pressure over time has been shown to correlate with increased discomfort and reduced concentration when driving (Moes, 2007). As an individual sits for a prolonged period of time in an automobile seat, compression of the soft tissues and seat foam increase as reflected in an increase in total seat pressure. Compression of the soft tissues increase the hydrostatic pressure and shear stress at the buttock-seat interface and have been shown to have a negative effect on capillary blood flow, nerve conduction and interstitial fluid movement, all which may be sources of discomfort (Chow and Odell, 1978, Oomens et al., 1987, Levine et al., 1990). While no specific discomfort data was collected for the gluteal and thigh regions in this study, it is likely that soft tissue compression contributed to the increase in overall discomfort found in all participants.

Normalized discomfort data collected at three points during the study reflects the general results of previous literature on prolonged sitting, that being a slow increase in overall discomfort over time (Na et al., 2005). However, the results for low back discomfort over time specifically differ from what has been reported in the past. While males continued their pattern of slowing increasing discomfort over time, females reported an initial increase in discomfort after the first hour of simulated driving which then decreases after the second hour of sitting. Two factors may have contributed to these results. First, from the lumbar posture data collected in this study, it was evident that female subjects changed their lumbar posture midway between the two hours of prolonged sitting. This gross postural change may have helped female subjects minimize the load on pain generating structures. While erector spinae activity was not monitored in this study, it is possible that female subjects were experiencing discomfort secondary to muscular irritation which prompted an increase in lumbar flexion. Secondly, the second passive lumbar flexion trial taken between the two simulated driving trials may have provided female subjects with relief. There is much support for the relief of low back discomfort in manual therapy literature with techniques such as passive stretching and mobilization (Koes et al. 1992, Brontford et al., 2004). It is possible that the second passive measurement trial acted as a treatment. Callaghan et al. (2001) discussed standing and walking as ideal rest activities from prolonged sitting. It is possible that in the short period of time participants stood up and walked over to the passive lumbar flexion jig and back provided relief to participants. The interruption of the two hours of simulated driving was a limitation of this study.

It is important, however, to note that while subjective ratings of discomfort improved in the low back area for women, trends of decreased stiffness continued to occur until the end of the experiment. Thus, while many would consider sitting postures with increased lumbar spine flexion risky, discomfort may not be the best indicator of passive tissue changes or their associated potential for pain generation. Previous studies have documented that people adopting more extreme low back postures do not necessarily report higher discomfort (Keegan 1953). It is well known that spine ligaments are a feasible source of pain (Bogduck, 1983), thus, the authors would have expected females to report higher levels of low back discomfort due to the decreased lumbar spine stiffness measured at the end of the experiment. Back muscle activity during simulated driving was not studied in this experiment. It is possible that women were experiencing discomfort secondary to low level muscular activity which would be relieved by increasing lumbar flexion and increasing the load on passive tissues. In both of the above situations, increased lumbar support should assist in promoting a healthier lumbar spine posture as well as decrease erector spinae demand during driving. Further investigation in this area is therefore warranted.

There are a few limitations to this study, which require discussion. For prolonged measurement periods, questions will undoubtedly arise about drift, the influence of body heat and movement of the tri-axial accelerometers with respect to the skin. To address these questions the accelerometers were recalibrated at the end of each collection period and compared to the calibration completed immediately preceding the collection period. No significant differences were found in calibration values during data collection, thus it is assumed that these concerns are negligible for the conditions of this study.

To minimize displacement of the accelerometer with respect to the participants' body, great attention was placed on the instrumentation and preparation of the subjects. For example, during mounting, all efforts were taken to ensure that the accelerometer was mounted as flat as possible against the back to minimize rotation about the y-axis of the device (movement in the sagittal plane of the subject). Foam cut outs were placed beside the device to stabilize it before taping to ensure that the accelerometer did not move with respect to the skin as the subject interacted with the backrest. Considering male and female participants were collected in a random fashion with identical set up techniques, it is unlikely that the difference in lumbar spine angles measured by accelerometer were due to equipment error.

There are two limitations with the passive range of motion measurement used in this study. The first was that determining end range of motion is a subjective rating on the part of the experimenter or subject. To minimize the effect of this limitation all passive range of motion measurements were conducted by the same experimenter, who was trained in this technique. In addition, visual feedback from the force transducer output on the oscilloscope was used by the experimenter to gauge the amount of passive resistance to lumbar flexion at the end range of motion.

The second is that due to the time-varying nature of the viscoelastic properties of in-vivo tissues, a change in position will have an effect on stiffness measurements. Thus, it is possible that having participants stand up and walk over to the passive range of motion jig and then return to the automobile seat might have affected the passive range of motion measurements and potentially lumbar and pelvic postures observed during the second hour of sitting as well.

Further, the passive test itself may have influenced the second hour of exposure through passive stretching of the lumbar spine. Unfortunately at the time this experiment was conducted instrumentation was unavailable to measure lumbar stiffness without moving the participant. In order to minimize alterations to the viscoelastic status of the spine participants were moved as quickly and carefully as possible from the seat to the jig and vice versa.

Conclusion

In conclusion, as the average length of time society spends sitting in a car and awareness of the risks of low back pain secondary to prolonged sitting increase, a rigorous study of the mechanical factors that may be contributing to back pain generation and the interventions that have the potential to prevent them becomes even more critical.

This study examined the effect a two hour simulated driving trial had on passive lumbar spine stiffness. Postural differences between genders were demonstrated in this study. Passive stiffness appeared to increase in males over time but decreased in females over time. In order to reduce the potential for injury to the passive elements of the spine during prolonged driving, gender specific ergonomic interventions, such as improvements in lumbar support for the automobile seat are indicated. Further, based on the results of this study it would appear that increasing the number of rest breaks while driving, preferably once per hour, would be advisable.

This work contributes information that can be used for the design of back supports and automobile seats and to the overall understanding of spine biomechanics and injury prevention in prolonged driving.

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