Evaluation of a novel thoracic support for police officers during prolonged simulated driving exposures

by

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AUTHOR`S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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ABSTRACT

Background: There is a high prevalence of injury and low back pain prevalence associated with professional drivers, including mobile police officers. In particular, the reduction in lumbar lordosis has been hypothesized as a contributing risk factor for injury during prolonged seated periods. Furthermore, the use of the mobile data terminal (MDT) and the protective equipment worn by officers creates a unique interface between the occupant and the car seat.

Purpose: To evaluate a novel thoracic support that was designed to address the unique seated working demands of mobile police officers.

Methods: Fourteen participants: 7 male (21.3 (1.9) years, 1.71 (0.06) m, 75.1 (9.3) kg) and 7 female (23.3 (4.4) years, 1.69 (0.06) m, 68.2 (7.7) kg) were recruited from a university student population. Participants attended two 120 minute driving simulations on separate days; using a standard Crown Victoria Interceptor seat and the same seat equipped with a retrofitted surface mounted thoracic support. Time-varying spine postures, seat pressure measures and perceived discomfort were measured.

Results: The introduction of a thoracic support changed postures, reduced lower seat back interface pressures but did not reduce discomfort compared to a standard seat during a 2 hour exposure period. Average discomfort scores were low with all values below 10mm out of a possible 100mm for both seating conditions. Discomfort was found to have small increases over time in the neck and right thigh with the support, but mean values remained low (under 3mm). Lumbar angles became more flexed with the support compared to a standard seat. Posterior pelvic rotation was reduced in female participants while in males there was greater posterior pelvic rotation with the support. There was a reduction in interface pressures on the bottom half of the seat back, the area where the duty belt is in contact with the seat.

Conclusions: The postural and seat interface information support further field evaluations using a retrofitted thoracic insert as an in-vehicle ergonomic intervention for police officers. Further investigations focussed on prolonged exposure to the intervention will guide future design iterations.

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CHAPTER 1.0 Introduction

Prolonged driving has been associated with musculoskeletal injury risk (Porter and Gyi, 2002). One of the identified risk factors is the prolonged fixed postures assumed during seated periods, which are associated with increased low back discomfort (El Falou et al., 2003). The reduction in lumbar lordosis that occurs during sitting (De Carvalho et al., 2010; Keegan et al., 1953; Dunk et al., 2005) has been associated with increased intradiscal pressure (Makhsous et al., 2003; Andersson et al., 1974) and increased tension on the posterior elements of the spinal column (Andersson et al., 1974; De Carvalho et al., 2010). Law enforcement officers and their job demands often require long periods of time seated in cruisers. It has been shown that up to 50 percent or 6 hours of an officer's 12-hour shift on average is spent seated in their vehicle (McKinnon et al., 2011a). Individuals who drive more than 20 hours a week for their job are absent from work with back pain at a rate six times higher than those who drive less than 10 hours per week as part of their job (Porter and Gyi, 2002). Discomfort questionnaire responses have shown that the low back support as a seat feature, computer use and the duty belt worn by officers were the three greatest sources of discomfort during in-vehicle activities (Donnelly et al., 2009). Further, low back discomfort has been shown to decrease by 35 percent in prototype automobile seats with an active lumbar support system and foam structural modifications compared to a standard seat (Donnelly et al., 2009).

Past studies in automotive sitting have shown that a lumbar support can have favourable outcomes on reducing low back muscle activation (Kingma and van Dieën, 2009), intradiscal pressure (Andersson et al., 1974) and discomfort reporting (Donnelly et al., 2009; Chen et al., 2005). In a study conducted by Porter and Gyi (2002), drivers of cars with an adjustable lumbar support had fewer days absent with low back pain than drivers without the low back support.

However, the issue is complicated by gender differences in seated postures (Dunk et al., 2005; Callaghan et al., 2010) as well as the equipment worn by officers (Donnelly et al., 2009). The duty belt and protective vest creates a unique barrier or interface between the seat and the vehicle occupant in both the lumbar and thoracic regions. Therefore, an intervention to improve seated lumbar posture and reduce perceived discomfort while accommodating the body armour and duty belt was the focus of this thesis.

CHAPTER 2.0 Purposes

The purpose of this project was to examine the potential of an automotive retrofit thoracic support specifically designed to accommodate the required body armour and equipment worn by police officers. Specifically, the design goals of the support were to decrease discomfort, create lumbar and pelvic inclinations similar to reported non-commercial drivers and closer to neutral postures, while not limiting postural adjustments to accomplish secondary tasks such as MDT usage. A secondary purpose was to quantify gender specific responses to the intervention.

CHAPTER 3.0 Hypotheses

1.) The seating intervention will increase the amount of lumbar lordosis compared to a standard seat and gender will not have an effect on lumbar angles. There is evidence that lumbar supports in both automobile (De Carvalho et al., 2010; Reed and Schnider, 1996; Andersson et al., 1974) and office seats (Carcone et al., 2007) increase the amount of lumbar lordosis during sitting. It has also been documented that there are gender differences in trunk posture during prolonged automotive seating (Callaghan et al., 2010; Viano, 2002) however, there were no significant differences in lumbar angles (Callaghan et al., 2010; Gruevski et al, *in press*).

2.) With the thoracic support, seat back interface pressures will be higher and seat pan pressures will be lower compared to a standard seat. Gender will not have a direct effect on interface pressures. The use of a lumbar support has been shown to reduce ischial pressure independent of seat pan angle (Shields and Cook, 1988). In office seating, males have been shown to have more diffuse pressure distributions while women have more focal pressure distributions under the load bearing ischial tuberosities (Dunk et al., 2005). However, in vehicle seating there has been no significant pressure differences between genders (De Carvalho et al., 2011).

3.) Discomfort will be lower in the intervention condition and will not depend on gender. Previous studies involving lumbar supports in office chairs (Carcone et al., 2007), automobile seats (De Looze et al., 2003) and active motion devices (Donnelly et al., 2009) have shown a reduction in discomfort compared to control seats. Significant differences in patterns of discomfort between genders have not been demonstrated in automotive seats (De Carvalho et al., 2011; Gruevski et al., *in press*). Differences in discomfort exceeding 9 mm will be considered clinically significant based on the criteria outlined by Kelly (1998).

4.) Lumbar postures will become more flexed, interface pressures will increase and discomfort scores will increase over the course of the simulation. It has been shown that postures change over the course of prolonged driving exposures (Callaghan et al., 2010; De Carvalho et al., 2011; Gruevski et al., *in press*). Prolonged exposures have been shown to increase posterior pelvic rotation, increase lumbar flexion and increase extension in the hips and knees (Callaghan et al., 2010). Additionally, it has been shown that interface pressures increase over prolonged driving exposures (Callaghan et al., 2010). Previous studies have shown an increase in discomfort over the course of a prolonged driving simulation (De Carvalho et al., 2011; Callaghan et al., 2010; Gruevski et al., *in press*).

CHAPTER 4.0 Literature Review

4.1 Low back injuries

Low back musculoskeletal injuries represent a significant financial burden to the healthcare system, government agencies and employers. Workplace musculoskeletal disorders (WMSDs) include a variety of pathologies relating to bones, muscles, tendons and ligaments of the body. In 2009, WMSDs accounted for 44 percent of all injury claims in Ontario (Ministry of Labour, 2011). In 2009, WMSDs caused over 900 000 work days lost and cost 111 million dollars to the Workplace Safety and Insurance Board (Ministry of Labour, 2011). The low back is an area of particular interest with almost a quarter of all injury claims made to WSIB in 2009 affecting this area (WSIB, 2009). In 2009, 10.4 percent of all injury claims to WSIB occurred in occupations that involve prolonged seated exposures such as clerical, business and administrative positions (WSIB, 2009).

4.2 Prolonged sitting risk factors

A link has been demonstrated in the literature between prolonged seated exposures and low back pain (Alperovitch-Najenson et al., 2010; Anderson et al., 1974; Callaghan et al., 2010; De Carvalho et al., 2010; Reed and Schneider, 1996). Beginning in the 20th century, there have been increases in the number of occupations that require workers to remain seated for a large proportion of the workday (Corlett, 2006). In a recent review, Lis et al. (2007) demonstrated that workers who spend more than half their day sitting had higher rates of low back pain than the general population. During sitting, the lumbar lordosis flattens (De Carvalho et al., 2010; Keegan et al., 1953; Makhsous et al., 2003). Some authors have hypothesized that the posterior rotation of the pelvis and reduction in lumbar lordosis may lead to increased tension on the passive tissues on the posterior aspect of the spine (Keegan, 1953), increased disc pressure

(Anderson et al., 1974; Makhsous et al., 2003; De Carvalho et al., 2010) and increased pressure on the ishium and coccyx (Goossens et al., 2000). Additionally, the flexion of the lumbar spine required in seated postures has been demonstrated as a potential risk factor for low back pain by several researchers (Anderson et al., 1974; Callaghan et al., 2010; De Carvalho et al., 2010; Reed and Schneider, 1996). There is also an association between uncomfortable seating and neck and upper back pain in bus drivers (Alperovitch-Najenson et al., 2010). In the same study, the low back area was the only region with a high prevalence of pain (Alperovitch-Najenson et al., 2010).

The relationship between posture and disc degeneration has been examined in cadavers. In a study conducted by Farfan et al. (1972), 46 cadaveric spines were separated into two groups with 50 degrees or greater lumbar lordosis, or less than 30 degrees of lumbar lordosis. Although the study was descriptive and there is no discussion of statistical significance, the authors found that annular ruptures were more common in spines in the flattened (less than 30 degree) group.

4.3 Prolonged driving injury risks

Prolonged driving has been associated with increased low back pain (Porter and Gyi, 2002). Individuals who drove more than 20 hours a week for their job were absent from work with back pain at a rate six times higher than those who drove less than 10 hours per week as part of their job (Porter and Gyi, 2002). Compared to controls, males with occupations requiring half the day in a vehicle, were 3 times as likely to develop a herniated lumbar disc (Kelsey and Hardy, 1975). Professional drivers spend the vast majority of their working shift in their vehicle, either driving or performing work related tasks (McKinnon et al., 2011a). There is an increased prevalence of back pain associated with professional drivers (Alperovitch-Najenson et al., 2010; Chen et al., 2005; Krause et al., 2004; Okunribido et al., 2007; Pietri et al., 1992; Porter and Gyi,

2002) including bus and taxi drivers. Police officers as a group are considered prolonged drivers. Rural officers have been shown to have annual mileage greater than 40000km, with 18% of exposed officers always or often experiencing low back pain (Gyi and Porter, 1998).

The operation of a vehicle involves risk factors that are unique when compared to other prolonged seated working environments. Due to the required involvement of both the upper and lower extremities during driving and the constrained seated design for safety, seated positions have been shown to be more non-varying when compared to office seating (De Carvalho et al., 2011). The intervertebral discs garner nutrients when exposed to pressure changes brought on by postural shifts in the spine (Corlett, 2006). Therefore, it has been hypothesized that postural shifts should be included in seated work to maintain spine health (Corlett, 2006; Pynt et al., 2001). Another factor unique to vehicle seating is the involvement of the feet; depressing the clutch and shifting gears have been shown to increase intervertebral pressure (Andersson et al., 1974). There is also exposure to road vibration during the operation of the vehicle that may exacerbate low back pain and increase injury risk (El Falou et al., 2003; Lis et al., 2007). Both magnitude and duration of exposure to occupational vibration in combination with prolonged sitting have been associated with increased incidence of low back pain (Lis et al., 2007). Additionally, the presence of vibration and uncomfortable seating may lead to a decrement in driving performance, which underscores the importance of comfortable seating (El Falou et al., 2003).

4.4 Driving Postures

The injury risks and potential for low back pain associated with prolonged driving highlights the importance of quantifying driving postures. A recent study conducted by De Carvalho et al. (2010) compared the lumbar angles of males in standing positions to sitting in an automobile seat. The lumbar lordosis was found to decrease an average of 43 degrees and sacral inclination decreased by 44 degrees between standing and sitting in an automotive seat (Figure 1) (De Carvalho et al., 2010).

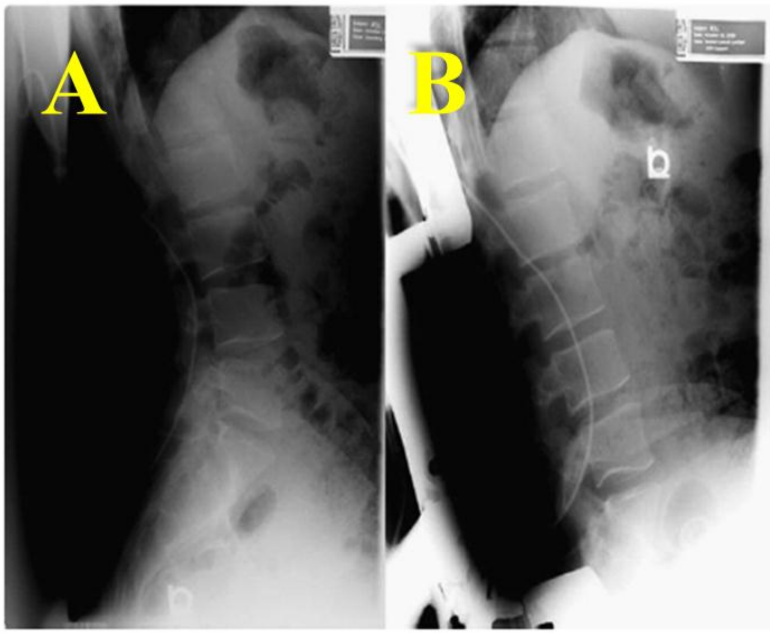


Figure 1. Radiograph of a male participant demonstrating a decrease in lumbar lordosis in sitting in an automobile seat (B) compared to standing (A) [from De Carvalho et al., 2010]

The intervertebral joint angles at the L5/S1 level were nearly the same as in standing values, suggesting substantial strain on the posterior aspect of the intervertebral discs at the L4/L5 level (De Carvalho et al., 2010). Hip and knee angles may also be of importance when considering spine postures. Keegan (1953) hypothesized that thigh flexion may rotate the pelvis posteriorly due to the limited length of the gluteal muscles. Additionally, knee angles greater than 90 degrees have been discussed to have similar effects on the pelvis (Reed and Schneider, 1996). In a study conducted by Chen et al. (2005) drivers who sat with a greater angle between the back and thigh were less likely to have back problems than those who sat with greater hip flexion.

4.5 Gender Differences

Generally, there are anatomical (Coleman et al., 1998), postural (Dunk et al., 2005; Callaghan et al., 2010; Reed and Schneider, 1996) and tissue-based (Beach et al., 2005) gender differences in the lumbar and pelvic regions. Furthermore, there is evidence to suggest that there are postural differences between genders during sitting in both office and automotive sitting (Reed and Schneider, 1996; Dunk et al., 2005; Callaghan et al., 2010). In office sitting, men adopt more flexed postures of the lumbar spine than women, who tend to sit more upright (Dunk et al., 2005). This may speak to gender differences in injury pathways (Dunk et al., 2005). Men use the backrest of the chair more, while women sit more toward the edge of the seat while using a computer (Dunk et al., 2005). During simulated driving, males have more extended trunk and elbow postures, but no significant gender differences in lumbar or pelvic postures (Callaghan et al., 2010). During natural standing, females' pelvic inclinations are 10^{o} more anteriorly rotated and more lordotic than males (Callaghan et al., 2010). The increased anterior rotation of the pelvis is supported by Reed and Schneider (1996). In office seating, women have a more focal pressure distribution concentrated under the ischial tuberosities while males have a more diffuse pressure distribution (Figure 2) (Dunk et al., 2005).

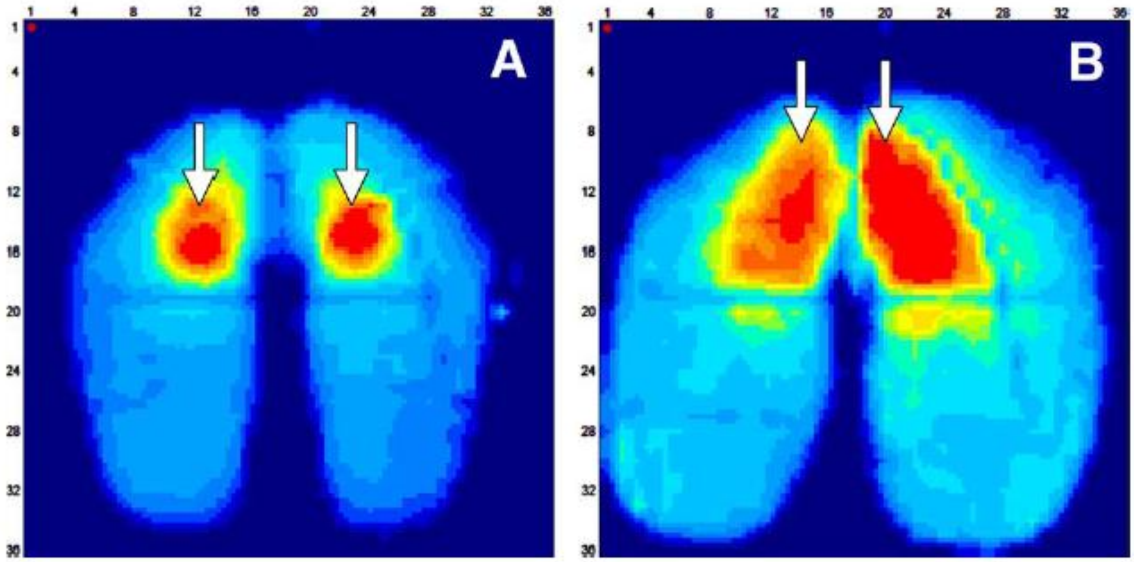


Figure 2 A typical seat pan pressure profile of a female (A) and male (B) subject [from Dunk et al., 2005]

Focal pressure distributions have been shown to be related to increased discomfort (De Looze et al., 2003). However, there is evidence that shows no difference in average interface pressure between genders in automobile seats (De Carvalho et al., 2011). The self-selected placements of car seat features have been shown to differ between genders (Reed and Schneider, 1996; Callaghan et al., 2010). Specifically, females were found to adjust the seat pan higher from the ground than males and position themselves closer to the steering wheel during lab simulated driving tasks (Callaghan et al., 2010). Given the relationship between postures and injury risk, it follows that there may be differences in loading patterns on the spine and differences in injury/pain pathways (Callaghan et al., 2010).

4.6 Discomfort/Comfort relationships to pressure and seat characteristics

There is a relationship between comfort and the material characteristics of car seats (Ebe and Griffin, 2001; Harrison et al., 2000). In addition to the safety aspects of vehicular seat design, comfort is among one of the most important aspects (Ebe and Griffin, 2001). In a recent study, Ebe and Griffin (2001) compared judgements of comfort to the foam density and stiffness characteristics of four office chairs. Low density foam in chair was judged to be less comfortable than the chair with the second highest density of foam (Ebe and Griffin, 2001). Low stiffness seats were found to be more comfortable than seats with high stiffness (Ebe and Griffin, 2001). The more linear the force deflection curve of the foam is, the more comfortable the seating surface will be (Ebe and Griffin, 2001). This is limited by the fact that an initial judgement of comfort within the first 10 seconds of sitting was evaluated. At least 2 hours of exposure to prolonged driving is required to differentiate between conditions (Gyi and Porter, 1999). Furthermore, these studies evaluated comfort as opposed to discomfort. The determination of comfort as an outcome variable has its own unique challenges. The relationship between discomfort and objective measures has been shown to have stronger associations than comfort (De Looze et al., 2003). Discomfort is associated with physical attributes, while comfort is associated with more abstract emotional constructs (De Looze et al., 2003). In a recent review, it was shown that seat interface pressures is the objective measure most closely correlated to perceptions of discomfort (De Looze et al., 2003).

4.7 Car seat design

Car seats and ergonomic interventions targeted for use while driving produce unique challenges compared to office chairs (Chen et al., 2005; Mills, 2007; Andersson et al., 1974; Harrison et al., 2000). The position of the driver is largely determined by the field of vision and the operation of the controls of the vehicle (Andersson et al., 1974). Car seats have a role in the protection system of a vehicle in the event of a collision (Viano, 2002; Mills, 2007; Harrison et al., 2000). Compliance of the seat back material and the position of the head restraint are designed to prevent whiplash injuries during low speed collisions while the posterior rotation of the seat back frame is designed to absorb energy and decelerate the occupant during high speed collisions (Viano, 2002). The foam used in car seats is specific to damp the vibrations of the vehicle (Mills, 2007). It has been recommended that car seats be designed to attenuate frequencies between 1 and 20 Hz (Harrison et al., 2000) as this range encompasses the natural frequencies of the musculoskeletal system. Car seat backs typically have a backward inclination of about 20 degrees beyond vertical in order to keep the roof of the vehicle low (Mills, 2007) and to maintain a space between the occupant's head and the backrest (Viano, 2002). This results in the occupant situated in a semi-recumbent position during the operation of the vehicle (Mills, 2007). The recommended car seat positioning involves seat back inclination of 100^{o} relative to the horizontal (Harrison et al., 2000), a seat pan inclination of 5^{o} above horizontal (Goossens et al., 2000; Harrison et al., 2000) and a 5 cm lumbar support perpendicular to the backrest of the seat (Andersson et al., 1974; Harrison et al., 2000) elliptical in shape located at the top of the posterior superior iliac spine (Harrison et al., 2000) (Figure 3).

Figure 3. Recommended driver's seat back and seat pan inclination angles

A challenge with automotive seat design is the differences in anthropometrics between individuals (Andersson et al., 1979). Automotive seats are usually designed with respect to the 50th percentile male (Harrison et al., 2000) and lack adjustability in lumbar support location (Porter and Gyi, 2002).

4.8 Lumbar supports in office chairs

The efficacy of a lumbar support is typically evaluated in terms of posture (Coleman et al., 1998; Carcone and Keir, 2007), muscle activity (Makhsous et al., 2003), interface pressures (Carcone and Keir, 2007; Shields and Cook, 1988) and discomfort measures (Carcone and Keir, 2007). In a study conducted by Carcone and Keir (2007), lumbar angles and discomfort were measured during a typing task in an office chair with 3 levels (small, medium, large) of lumbar support. The authors found that there was a significant relationship between increasing lumbar support size and increased surface measures of lumbar lordosis. Coincident with the postural responses, ratings of perceived discomfort also decreased as lumbar support increased. The use of backrests and armrests has been shown to reduce intradiscal pressure during sitting (Wilke et al., 1999). The use of a lumbar support has been shown to reduce ishial pressure on the seat pan independent of seat pan angle (Shields and Cook, 1988). In a recent study conducted by Coleman et al (1998), 123 participants were asked to self-select the height and depth of an adjustable lumbar support in an office setting. The height of the self-selected lumbar support in office chairs was found to be associated with BMI and not stature, where people with higher BMIs placed the lumbar support higher (Coleman et al., 1998). No gender differences were found between males and females with preferred lumbar support placement (Coleman et al., 1998). The authors recommend an adjustable support between 150 to 200mm above the compressed base of the seat.

4.9 Lumbar supports in cars

There is some evidence to suggest that lumbar supports in car seats may be beneficial in terms of reducing discomfort (Chen et al., 2005; Donnelly et al., 2010), promoting lordotic postures (Reed and Schneider, 1996; Andersson et al., 1974) and reducing muscle activity (Kingma and van Dieën, 2009; Andersson et al., 1974). Specific to police cruisers, the lumbar support was the in vehicle seat feature that caused the greatest amount of musculoskeletal discomfort in a recent survey of a Canadian police force (Donnelly et al., 2009). The stiffness, vertical location and the pressure created by the lumbar support were the features that resulted in the greatest musculoskeletal discomfort (Donnelly et al., 2009). In a recent survey of professional drivers, those who use a removable foam lumbar support were less likely to suffer from back pain than those who did not (Chen et al., 2005). A mechanical lumbar support in vehicle seating has been shown to decrease lumbar and pelvic discomfort significantly when compared to a control seat (Figure 4) (Donnelly et al., 2009).

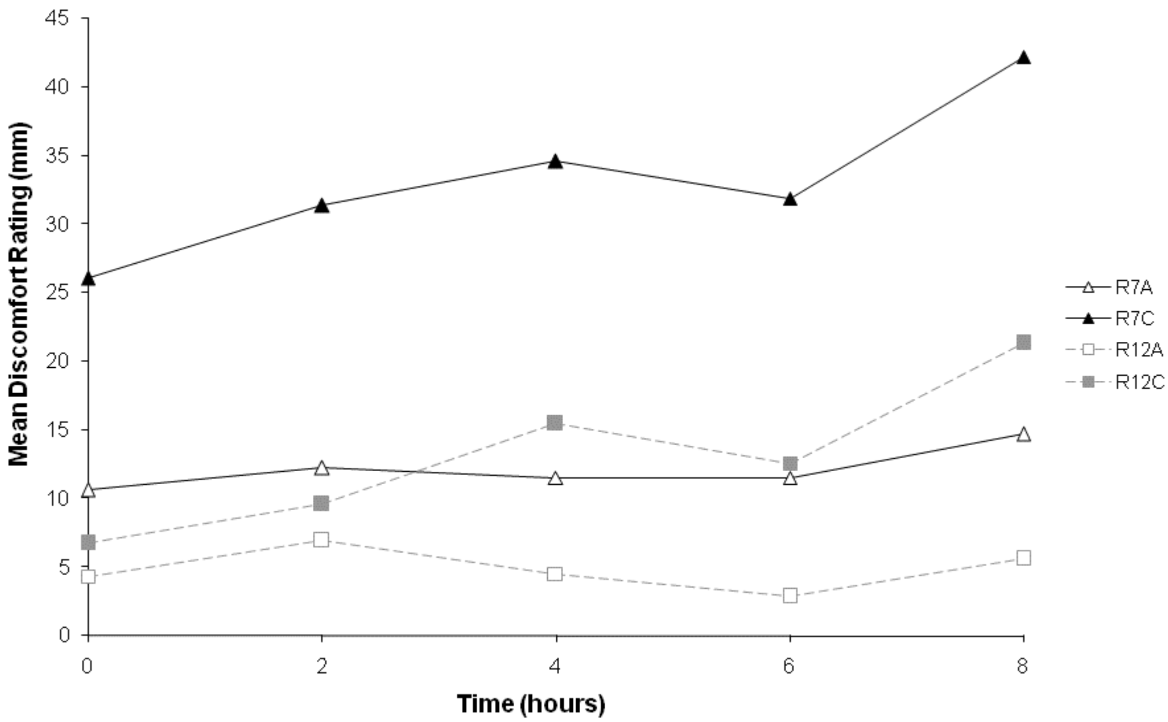


Figure 4 Mean pelvic (R12) and low back (R7) discomfort in the ALS (A) and control seat (C) [from Donnelly et al., 2009]

Drivers of cars with an adjustable lumbar support reported fewer days absent with low back pain than drivers without the low back support (Porter and Gyi, 2002). In a recent investigation of RCMP officers, it was recommended that officers use the lumbar supports in their vehicles and that backrests should be designed with officers and their task demands in mind (Kumar and Naryan, 1999). In a lab simulator of an automobile, it has been shown that both intervertebral disc pressure and muscle activity at the thoracic (T5, T8, T10) and lumbar (L1 and L3) levels decreased as the size of a lumbar support on the car seat increased (Andersson et al., 1974). Similarly, a foam lumbar support 25 mm deep in the transverse plane was found to reduce spine flexion by 5.4 degrees and resulted in significantly less posterior rotation of the pelvis (Reed and Schneider, 1996). Use of a moveable lumbar support has been shown to reduce fatigue in longissmus dorsi and multifidus and also reduced vibration when compared to a fixed backrest in lab simulated driving with vibration (Kingma and van Dieën, 2009). In the design of lumbar supports, it is recommended to build material behind L3 in and also to allow for a recess to accommodate the pelvis (Andersson et al., 1974). However, the additional tasks and equipment involved in police work have resulted in the lumbar support being identified as a problematic seat feature.

4.10 Law Enforcement

Law enforcement is a stressful occupation. In a survey of 1000 RCMP officers, nearly half of all respondents were exposed to a disturbing crime or accident in the past 12 months (Brown et al., 1998). In addition to the acute physical demands of law enforcement, many officers are required to spend long periods of time seated in cruisers combined with the usage of in-vehicle computing systems or mobile data terminals (MDT). In fact, up to 50 percent or 6 hours of an officer's shift is spent seated in a vehicle (Brown et al., 1998; McKinnon et al., 2011a) and up to 33 percent of this in vehicle time is spent performing data entry or retrieval activities with the MDT (Table 1) (McKinnon et al., 2011a).

Table 1 Percentage of time for in-vehicle activities in mobile police officers [from McKinnon et al., 2011a]

Activity	Mean Time (%)	*SD* (%)	Rank
Left-handed driving (right hand relaxed)	50.3	15.7	1
On-paper documentation	20.8	16.5	2
Right-handed MDT use	10.3	3.99	3
Two-handed driving	8.98	6.54	4
Vehicle entry/exit	3.09	1.29	5
Two-handed MDT use	2.78	1.81	6
Right arm lateral reach	1.49	0.81	7
Relaxed/traffic watch	1.20	2.08	8
Right arm forward reach	1.12	0.60	9

Notes. MDT—mobile data terminal.

It has been shown that the MDT is used up to 5 times more frequently when the vehicle is occupied by two officers (Hampton et al., 2005). While the MDT can increase productivity among officers (Hampton et al., 2005) and provides increased access to information and resources (Agrawal et al., 2003), the impact of in-vehicle computing and links to musculoskeletal pain need to be considered. In a survey of 58 officers from the Windsor Police Service, the mean discomfort associated with in-vehicle computer use was 64 percent with 100 percent representing extreme discomfort (Donnelly et al., 2009). The impact of the location of the MDT has previously been examined from a biomechanics perspective evaluating the muscular and postural demands and demonstrated that only modest improvements could be achieved due to the space constraints within the cruiser dictating the physical location of one-piece MDT units (McKinnon et al., 2011b). The relocation of the MDT was insufficient to reduce musculoskeletal discomfort and all tested configurations required similar shoulder elevation and low back postures (McKinnon et al., 2011b). Design of vehicle interiors and the location of mobile computers have also been discussed in terms of distraction (Dukic et al., 2005). The greater the angle in the transverse plane between the secondary task and the direction of vehicular movement, the greater time will be spent looking away from the road (Dukic et al., 2005).

The spatial constraints of the vehicle environment are further compounded by the body armour and duty belt required to be worn by officers at all times while on duty (Figure 5).

Figure 5 Personal police protective vest and a 4.75 kg duty belt with device surrogates of the same dimensions and mass as regular equipment

In a survey of 53 officers in the Windsor Police Force, it was shown that the duty belt, the side arm, radio and the body armour were the articles of equipment rated as causing the highest perceived discomfort by officers (Donnelly et al., 2009). Body armour was found to increase the risk of first onset low back pain by three times compared to officers that do not wear body armour (Burton et al., 1996). The duty belt used by officers may exacerbate existing symptoms of low back pain (Brown et al., 1998). With respect to seated posture, the duty belt and body armour create a unique interface between the occupant and the car seat when compared to other professional driving group and the non-commercial vehicle driving population.

4.11 Summary

Increased injury and low back pain prevalence is associated with prolonged driving. In particular, the reduction in lumbar lordosis has been hypothesized as a risk factor for injury in professional drivers, such as mobile police officers. There is evidence of gender specific responses to prolonged seated exposures. The implementation of lumbar supports has shown favorable outcomes in both office and automotive seats. The job demands and equipment requirements of police officers require an intervention strategy that provides lumbar support without building foam material in the lumbar region where the duty belt is worn. The results of the investigation will have practical application in the design of a potentially feasible intervention for mobile officers exposed to prolonged driving.

CHAPTER 5.0 Methods

The study involved two components; the fabrication of the thoracic support followed by its evaluation. The thoracic support (TS) was developed to mimic the built-in thoracic support in the Active Lumbar Support (ALS) seat by Leggett & Platt Automotive Group when applied to a Crown Victoria Interceptor (CV) seat. The ALS seat had foam structural modifications to the thoracic region as well as a shortened seat pan (Donnelly et al., 2009). In addition to the structural modifications, the seat had a mechanical component that translates both superiorly/inferiorly and anteriorly/posteriorly (Donnelly et al., 2009)

5.1 Thoracic Support Development

5.1.1 Seat Surface Scans

The development of the thoracic support began with generating point cloud meshes of both the ALS and CV seats. A rigid body with 6 active infrared markers (Northern Digital Inc., Waterloo, ON) was affixed to the surface of the head rest of the CV seat with tape. Four points (top right, bottom right, bottom left and top left) identified by seams on the seat were digitized relative to the head rest markers using a four marker digitizing probe (Northern Digital Inc., Waterloo, ON). As the ALS seat is a modified CV seat, the headrest was removed and attached to the ALS seat and the same four points were digitized on the ALS seat. The headrest was inserted to the same depth of the chair`s frame on each seat. The four digitized points on the seat were used to create a local coordinate system relative to headrest. Points were collected continuously in First Principles (Northern Digital Inc., Waterloo, ON) to scan the back rest surface of both the ALS and CV seats using a four marker digitizing probe (Northern Digital Inc., Waterloo, ON) by manually dragging the probe tip across the surface contours of each seat while sampling continuously (Figure 6). The probe was dragged along the seats both horizontally and vertically with care to not remove the probe from the surface of the seat and to not depress the foam on the seat back. Seat scans were completed with the four probe markers relative to the global coordinate system. Prior to collection, a pivot trial was completed where the end of the probe was constrained in a metal block and the four markers were pivoted about a fixed depression in the block. The tip of the probe was determined relative the tool's local coordinate system by performing a least-squares fit calculation to determine the centroid of the radius of the sphere created during the probe pivot trials in a custom made Matlab program (v.7.11.0, R2010b, Natick, MA, USA). The chair scans were transformed to represent the probe tip location in the global coordinate system. The points on the surface of the seat were transformed from the global system to be expressed within the local coordinate system of the headrest in a custom made Matlab program (v.7.11.0, R2010b, Natick, MA, USA). The headrest coordinate system was common to both seats and allowed the scans to be aligned in the same plane.

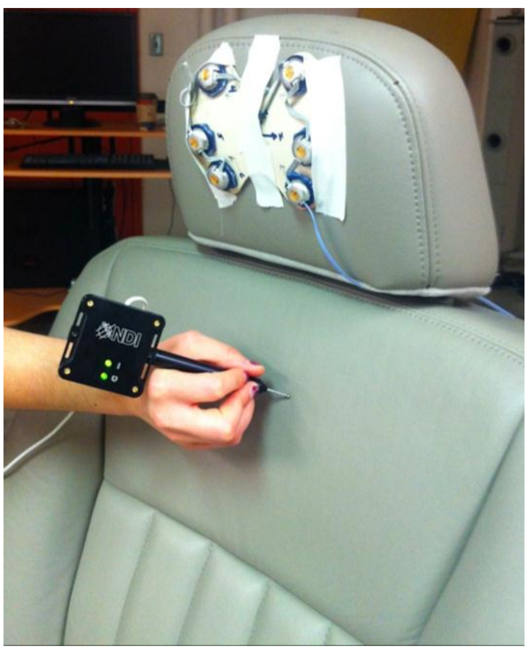


Figure 6 Seat surface scan completed with 4 marker digitizing probe

5.1.2 Mapped Differences

The development of the support implemented a comparison between the mapped differences of surface scans of the ALS and CV seats. A one dimensional linear interpolation was applied to the point clouds of each seat to create 100 equally spaced points along the vertical dimension of the backrest in a custom made Matlab program (v.7.11.0, R2010b, Natick, MA, USA). A linear interpolation was selected due to the fine resolution between data points (~ 1 mm). It was assumed that the profile followed a linear trend between digitized points. Interpolated slices of the seat were calculated every 5 mm. The aligned scanned surfaces were then plotted together and the distance between interpolated points in the depth dimension were plotted to determine shape of the difference between the control CV and the intervention ALS seat.

According to the manufacturer, the ALS seat has a vertical excursion of 5.7 cm and the support inflates to a maximum of 2.5cm compared to the resting position of the seat. The ALS seat was scanned in 6 different positions within its range of adjustability (Table 2).

Table 2 The order of chair scans on ALS seat. Note: 0mm of vertical excursion refers to the lowest position of the support

Scan	Vertical Excursion (mm)	Inflation of Support
1	5.7	deflated
2	5.7	max
3	3	deflated
4	3	max
5	0	deflated
6	0	max

The support mechanism in the ALS seat was measured both fully inflated and fully deflated, in both the highest and the lowest positions, with one intermediate condition (Figure 7).

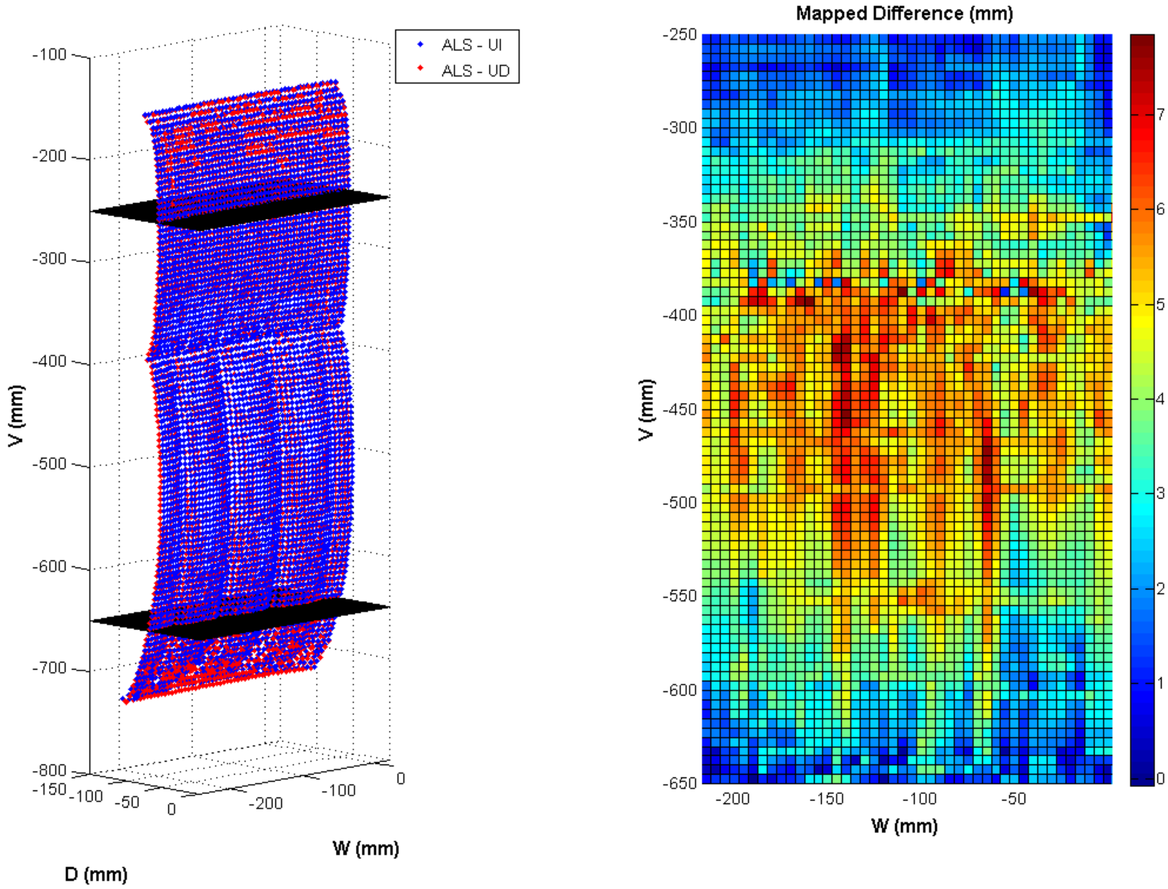


Figure 7 Interpolated scans of the ALS seat comparing the up and inflated (UI) to the up and deflated condition (UD)

Surface contour differences between thoracic support locations were determined and a composite series of slices of the ALS seat were used to compare with the Crown Victoria seat. The differences in depth between the two seats were calculated and represented the dimensions of the thoracic support in the ALS seat. The comparison between the highest vertical excursion and inflated ALS position was compared to the CV seat (Figure 8). The scanned difference in the depth dimension was determined to be approximately 15 mm. The edges of the thoracic support were tapered according to the scans such that the convex shape would accommodate trunk rotation during MDT usage.

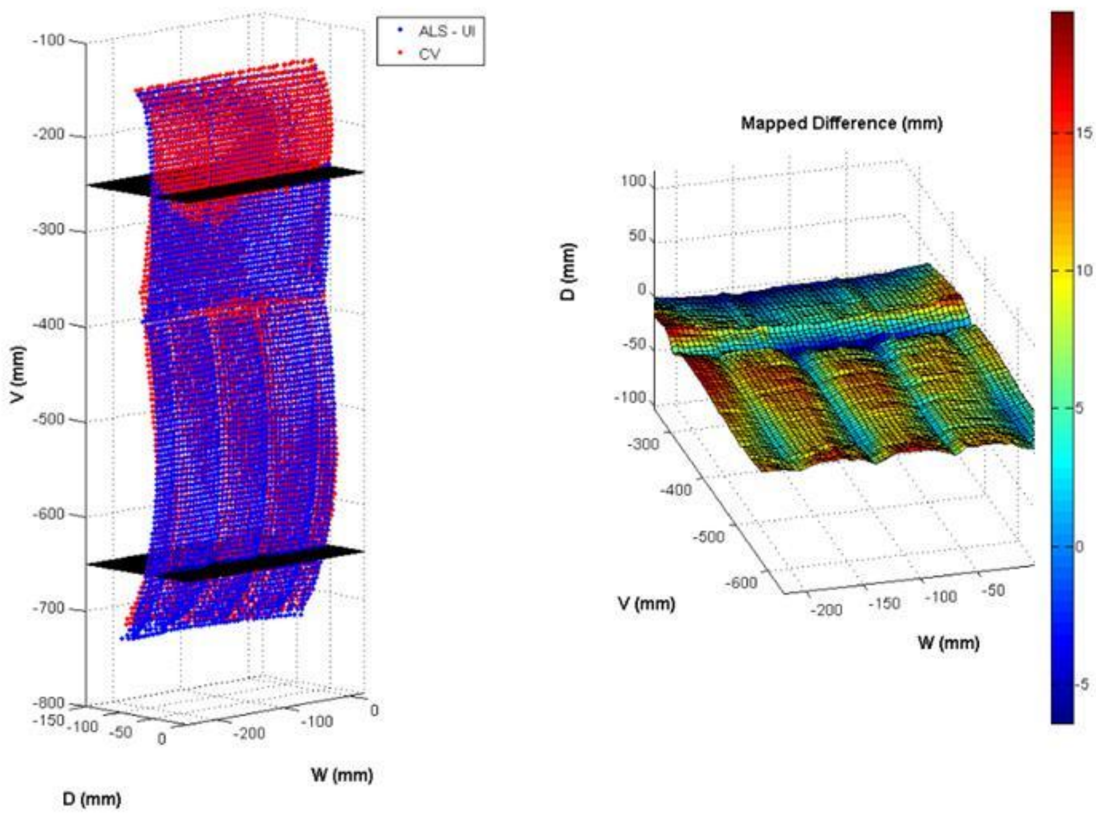


Figure 8 Mapped differences between the highest inflated ALS mechanism position compared to the CV seat. Mapped differences in the thoracic region are approximately 15 mm

5.1.3 Foam Selection

The deflection properties of the ALS seat in its fully inflated state was measured to select foam to mimic its properties. The deflection properties of the ALS seat in the maximally inflated setting was tested using an Ergofet hand force dynamometer (Hoggan Health Industries, West Jordan, UT, USA) (Table 3). The Ergofet was outfitted with 2 infrared markers (Northern

Digital Inc, Waterloo, ON) to measure the excursion of the foam during the application of 100N compared to the application of 0N. The deflection properties of three 2.5 cm thick closed-cell foam samples were tested overlying the surface of the Crown Victoria Interceptor and compared to the characteristics of the ALS seat (Table 3). Based on the deflection properties, the Evazote EV50 foam (Zotefoams, Croydon, Surrey, England) was used to build the prototype thoracic support.

Table 3 Excursion properties of closed-cell foam samples compared to ALS seat with 100 N of applied force

	Displacement (mm)
ALS	7.90
Minicel L200F	9.04
Plastazote LD24	8.74
Evazote EV50	8.44

5.1.4 Final Prototype

The scans indicated the thoracic support should be 15 mm thick. However, in order to compensate for the fact that the ALS seat was found to be stiffer than all of the foam samples tested, an extra 10 mm of thickness was added to the prototype since an exact foam match was not made. The foam was cut with an electric knife and the final prototype was covered with a light textile fabric (Reference No. 87821, Style: Trinidad, Signature Textiles, Val-Abel, Saint-Laurent Québec). A schematic with the dimension of the final prototype is depicted in Figure 9.

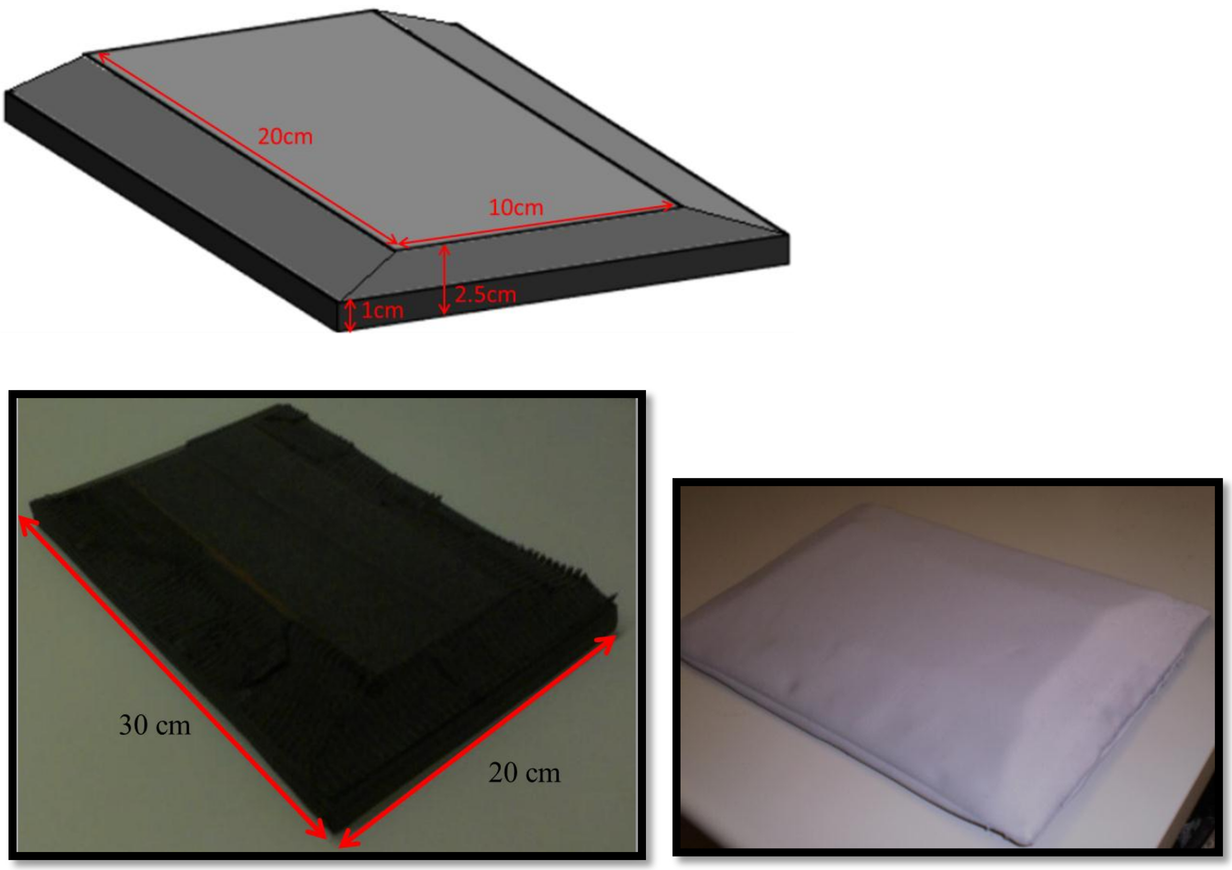


Figure 9 Schematic representation of support, cut foam thoracic support and covered support

5.2 Evaluation of Thoracic Support

5.2.1 Participants

Fourteen participants 7 male (21.3 (1.9) years, 1.71 (0.06) m, 75.1 (9.3) kg) 7 female (23.3 (4.4) years, 1.69 (0.06) m, 68.2 (7.7) kg) were recruited from a university student population. Participants were free of any low back or upper extremity musculoskeletal disorders or pain at the time of the study. Informed written consent was obtained prior to testing.

Participants were paired with similar absolute heights between genders (Table 4). Previous work examining prolonged driving exposures has demonstrated that when heights are matched between genders, postural differences in sitting disappear (Reed et al., 2000). In the current study, a two-tailed unpaired t-test compared standing heights of male and female participants. The heights were not statistically different ($p=0.2718$). Absolute participant heights represented a range of the male and female population. Ranges fell between 164cm-182cm and 161cm-178cm for males and females respectively. Percentile heights were used as a guideline to assess how far apart absolute matches were on a population basis (ANSUR Database Calculator, Open Design Lab, University Park, PA). A comparison was made between the percentile heights of collected female participants with the percentile heights of collected male participants using a female distribution. Table 4 depicts the percentile heights of collected females compared to the collected male heights using a female population distribution to represent an exact height match.

Table 4 Percentile heights of female collected and matched participants and absolute heights of male and female participants

Percentile Heights		Absolute Heights (cm)		Absolute Height Difference (cm)
Female		Male	Female	
Matched	Collected			
75	50	164	161	3
90	75	168	163	5
90	90	168	168	0
95	90	169	171	2
97.5	95	169	171	2
97.5	97.5	175	174	1
99	99	182	178	4
Average		170.7 (5.5)	169.4 (5.5)	P=0.2718

5.2.2 Protocol

Participants attended two 120 minute driving simulation test sessions separated by a minimum of 24 hours. Test sessions took place at the same time of day for each participant with the order of conditions randomized using a balanced minimization approach (Conlon and Anderson, 1990). The control session involved a standard Crown Victoria Interceptor seat and the intervention condition consisted of the control seat in conjunction with the thoracic support applied to the surface of the seat. Participants were not informed of the condition being tested. The thoracic support was secured to the seat with Velcro straps underneath the seatback pressure mat (which has an uncompressed thickness of 0.23cm) to obscure any visual clues to the participants (Figure 10). The support was adjusted for each participant and aligned with the bottom of the Kevlar vest.

Figure 10 General placement of thoracic support on seat back, beneath the pressure mapping pad

Each 2 hour session was collected in 8 blocks of 15 minute intervals and segmented into a total of 38 minutes of typing and 82 minutes of driving (Figure 11). This ratio represents 33 percent of the two-hour collection in order to replicate the proportion of MDT usage that takes place during a mobile officer's shift (McKinnon, 2011a). The typing tasks were comprised of two different durations. There was a prolonged typing task to represent report entry where the participants typed responses to long answer questions for a 10 minute period and occurred at the beginning and end of the session (Blocks 1 and 8). To replicate data retrieval and dispatch calls, intermittent typing tasks consisting of 1 minute of typing responses to short answer questions were triggered for every 4 minutes of driving. A 5V analog pulse trigger was used to indicate the initiation of each 15 minute block.

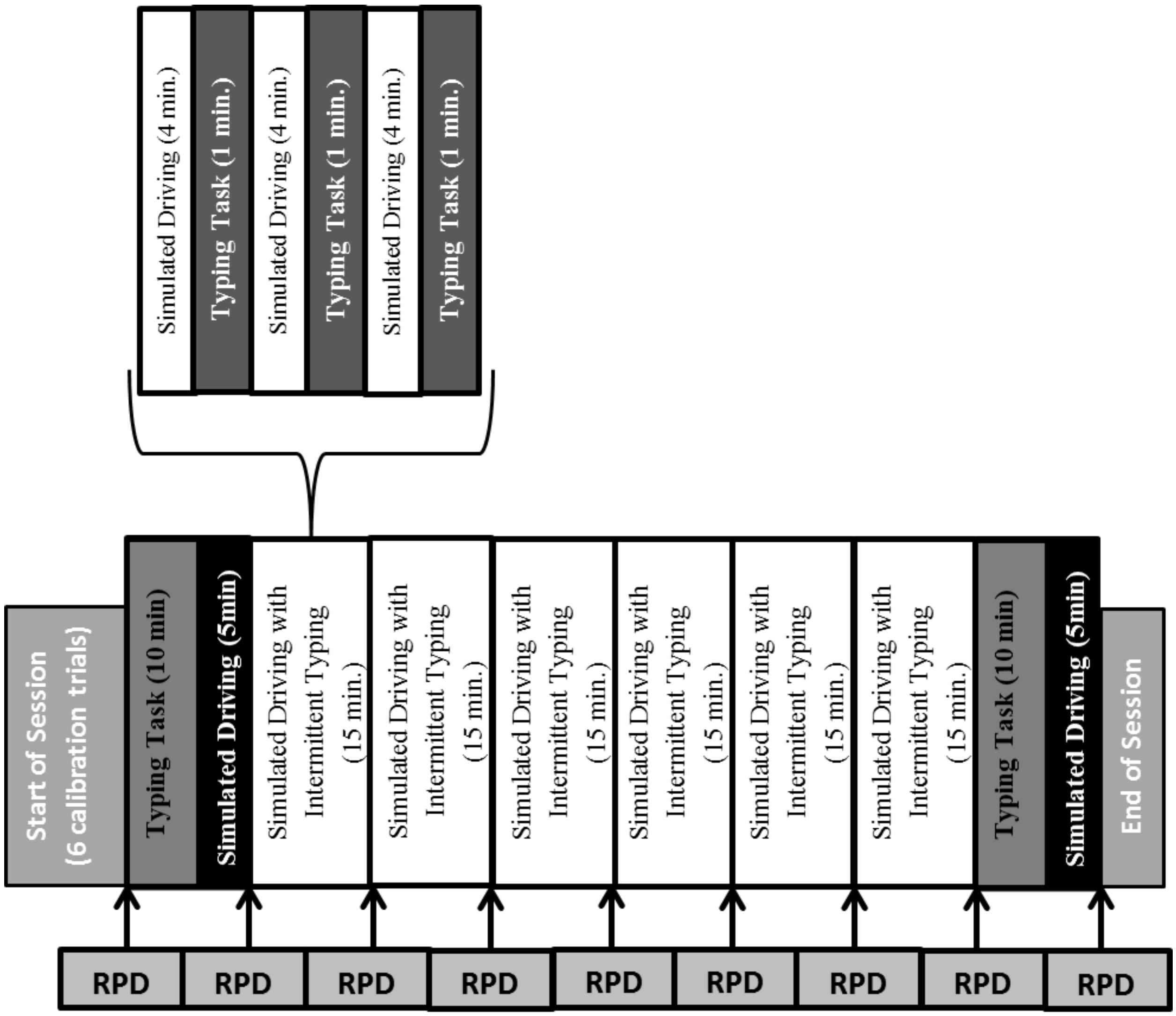


Figure 11 Outline of driving and typing protocol for both the backrest and control seat

The Ford Crown Victoria Interceptor was the police vehicle selected to design the parameters of the simulator. The driver's seat position was adjustable in the anterior/posterior direction within the constraints of an actual police vehicle with a Plexiglas cage in the backseat. The simulator was equipped with a donated MDT mount model currently used in police vehicles in a Municipal police force in Ontario (Figure 12). The MDT was located to mimic the location in a police cruiser using vehicle measurements obtained from a Waterloo Region Police Service cruiser.

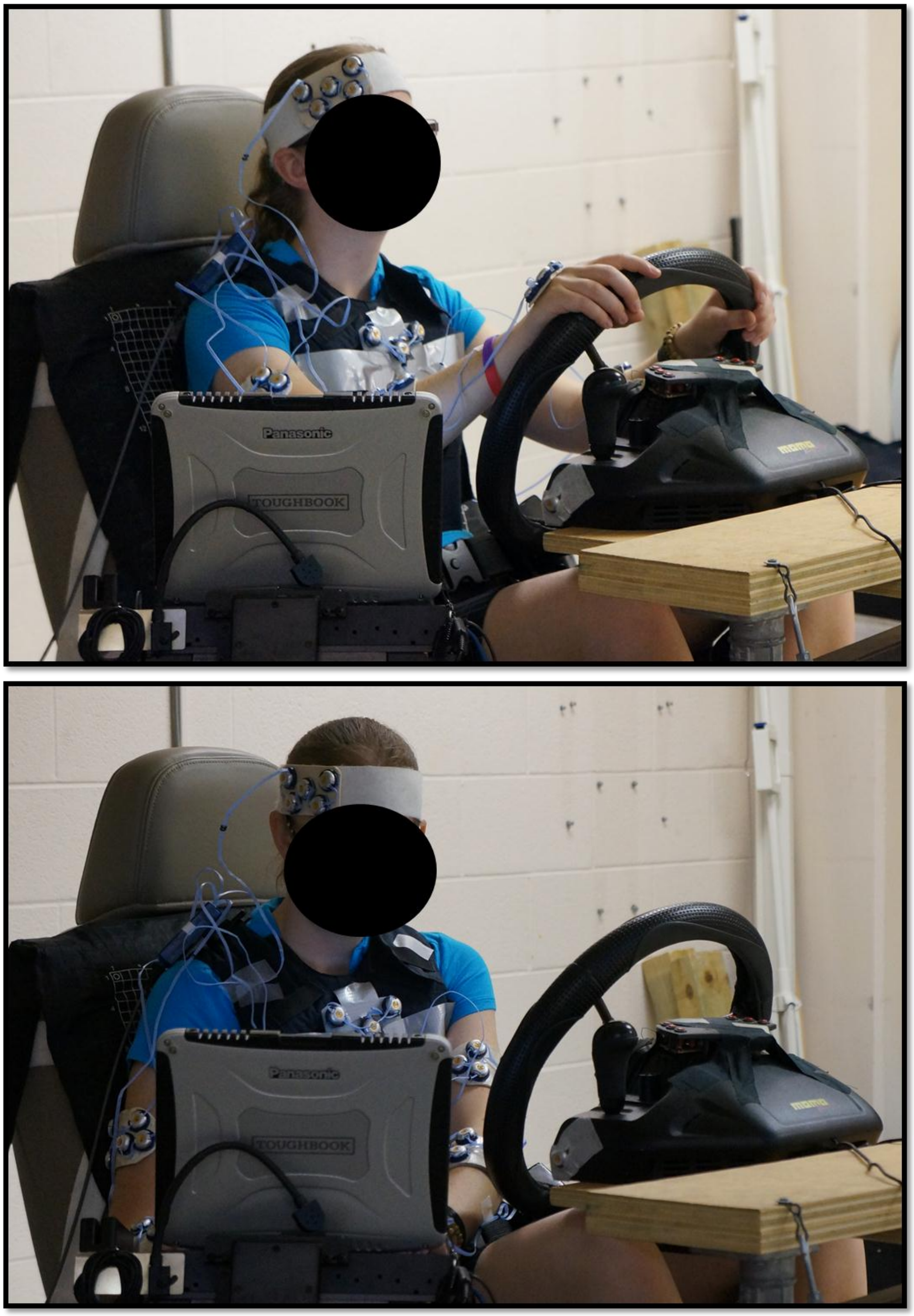


Figure 12 Lab simulator setup with control seat during simulated driving (top) and during a typing task on the MDT (bottom)

The height of the laptop, angle of the laptop screen and pivoting the laptop about its vertical axis were adjusted by the participant at the beginning of each session, within the same constraints available in a police cruiser. The vertical height of the laptop was constrained by 3 height settings on the MDT mount (low, medium, high) with a relative difference of 8 cm between the highest and lowest conditions. Table 5 displays the height settings selected by participants by condition.

Table 5 Self-selected height settings of MDT by seating condition

	MDT Height Setting	
Participant	**CV**	**TS**
1	M	L
2	M	M
3	H	H
4	M	M
5	M	M
6	M	M
7	M	H
8	M	M
9	H	H
10	M	M
11	H	M
12	M	M
13	H	H
14	M	M

The driving simulator was programmed using STISIM Drive (Systems Technology Inc., Hawthorne, CA, USA) to simulate highway driving. The simulation images were projected onto a 2.65 by 1.5 m screen located 2.1 m in front of the car seat. All participants were instrumented with a personal police protective vest and a 4.75 kg duty belt with device surrogates of the same dimensions and mass as regular equipment for the duration of the simulation. The device surrogates included; personal radio with holster, pepper spray canister, flashlight, retractable assault baton, pair of detainment handcuffs, firearm in holster with loaded ammunition magazine and additional ammunition magazine. The location of items along the length of the belt was standardized across all conditions and represented the functional basic suggested usage of a duty belt in active officers.

5.2.3 Lumbar Angles

Participants were instrumented with two tri-axial accelerometers (ADXL320, Analog Devices, Norwood, Massachusetts) for the duration of the simulation to calculate lumbar and pelvic angles. Two accelerometer calibrations were completed; an accelerometer instrument calibration and a participant calibration. The instrument calibration involved attaching the accelerometers to a flat surface and turning the complex about each of its 3 axes with the associated voltage being collected for a duration of 5 seconds. This voltage corresponded to the position of the accelerometers when completely flat in each axis and was used to normalize all experimental trials to measure the orientation of the accelerometers when deviated from this zeroed position. The accelerometers were affixed to the skin over the first lumbar vertebrae and the first sacral vertebrae with double-sided tape and further secured with hypafix tape over each unit. To scale the accelerometer data to provide measures of inclination, participants completed five 5 second static participant calibration trials, including: quiet standing, maximum lumbar flexion while standing, maximum lumbar extension, maximum lumbar flexion while sitting and maximum thoracic flexion while sitting. Standing lordotic posture was used as the neutral or "zero" position and time varying lumbar angles were normalized to the maximum lumbar flexion angle achieved in any of the calibration trials. A 16 bit analog to digital converter (Optotrak Data Acquisition Unit, NDI, Waterloo, ON) transformed the analog voltage outputs from the accelerometers into discrete signals. The accelerometer data were collected in eight continuous 15 minute blocks at 1024 Hz for the full 120 minute simulation. A 4th order Butterworth filter with a 1 Hz cutoff frequency (De Carvalho et al., 2011) was applied to the accelerometer data and then converted to normalized range of motion using a custom Matlab program (v.7.11.0, R2010b, Natick, MA, USA).The data were subsequently down sampled to 32Hz.

5.3.3 Motion Capture

A five camera-bank optoelectronic motion capture system (Optotrak Certus System, Northern Digital Inc., Waterloo, ON, Canada) was used collect kinematic data. The collection space was calibrated with a 16-marker cube and the cameras were aligned to the global coordinate system. The global coordinate system was positive in x, y and z to the participant's right, in front of the participant and upward respectively.

Participants were instrumented with 3 rigid bodies, each with 5 active infrared markers. The rigid bodies were used to track target data of the markers, on the head, torso and pelvis (Figure 13). The head cluster was attached to a headband, attached by Velcro straps. The torso cluster was attached overlying the Kevlar vest with double sided tape and further secured with duct tape on the vest. The pelvic marker cluster was attached on the outer surface of the left side of the duty belt by Velcro.

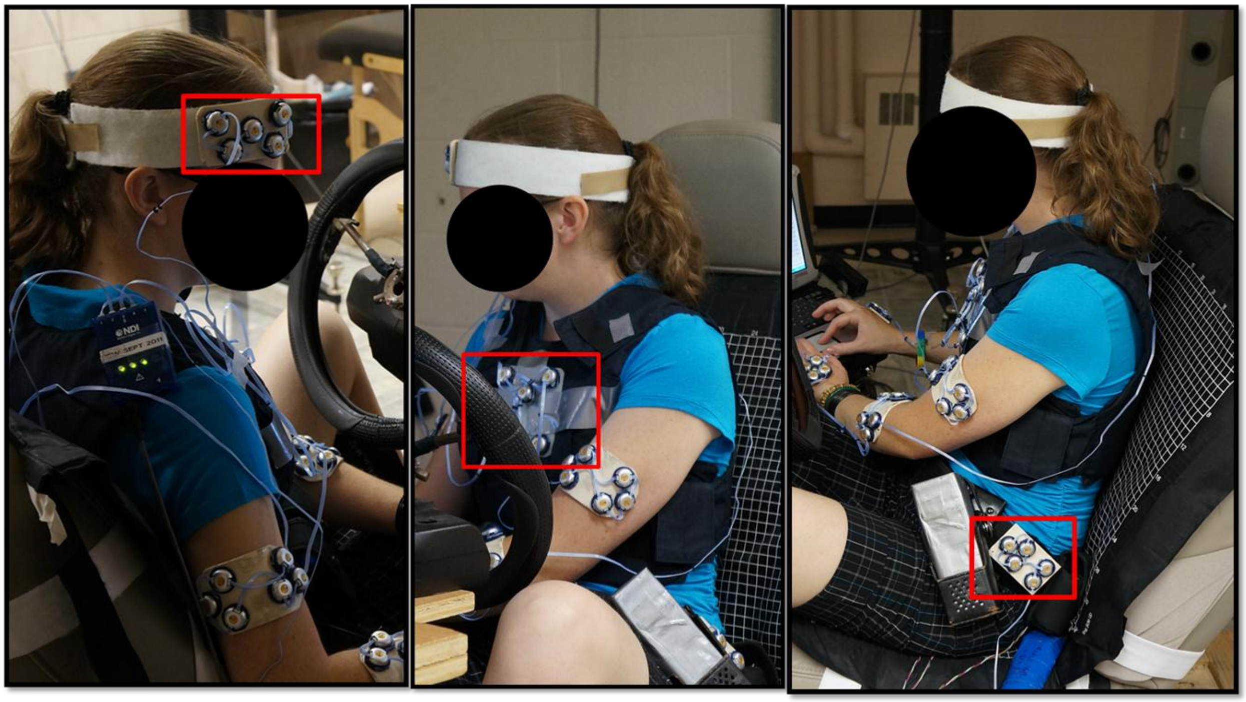


Figure 13 Marker cluster placement for the head, torso and pelvis segments

Anatomical landmarks were digitized on participants to designate the end points of each segment in Visual3D (C-Motion Inc, Visual3D Standard v4.96.4, Germantown, MD, USA) The pelvis was defined by the right and left greater trochanters and the right and left iliac crests, the trunk segment was defined by the left and right acromion and the left and right iliac crests and the head segment was defined by the left and right temporal styloid processes and two points superior to the right and left temporal styloid processes at the top of the head. An Euler angle decomposition sequence was calculated in Visual3D (C-Motion Inc, Visual3D Standard v4.96.4, Germantown, MD, USA) for the head relative to the torso and the torso relative to the pelvis with a positive rotation about the x axes representing extension, a positive rotation about y representing right lateral bend and a positive rotation about z representing left axial twist. A 5 second static calibration pose with the participant seated in the car seat with both arms outstretched was collected to establish the local coordinate systems for all the monitored segments. All tracking data were sampled at a frequency of 32 Hz. A 4^{th} order Butterworth filter with a 3Hz cut-off frequency was applied to the kinematic data (Callaghan et al., 2010).

5.3.4 Seat Interface Pressure

A capacitive pressure mapping system with two sensor mats (X3, XSensor Inc., Calgary, Alberta, Canada) was used to quantify the pressure interfaces on both the seat pan and seat back. The sensing surface of each mat measured 45.72cm by 45.72cm with a total of 1296 sensing squares per mat. The spatial resolution of each square was 1.27cm. Pressure measurements were collected continuously for the full 120 minute simulation in eight 15 minute blocks and sampled at 8 Hz. The X3 system was calibrated prior to collection. Each mat was positioned horizontally on a flat surface within a rigid calibration frame (XSensor Inc., Calgary, Alberta, Canada). The mat was loaded through an inflated interface that provided an equal pressure across the entire mat surface that enabled a calibration over a range of 10 to 200 mmHg of pressure. The pressure mat data were sampled through the X3 Pro interface adaptor connected directly to the collection computer via USB port. A synchronization cable was attached from the X3 Pro interface adaptor and connected to the Optotrak Data Acquisition Unit (ODAU) (Northern Digital Inc., Waterloo, ON, Canada). An external trigger option was selected in the X3 Pro software (X3 version 6, XSensor Inc., Calgary, Alberta, Canada), suspending the mats in cue until recording was initiated in First Principles (Northern Digital Inc., Waterloo, ON, Canada). This process insured the pressure data was synced with both the kinematic and the accelerometer data. To isolate the interface pressures on the upper and the lower part of the seat back, the upper half of the seat back (the top 18 x 36 sensors) and the bottom of the seat back(bottom 18 x 36sensors) were treated separately as dependent variables. The interface pressures during the two sessions were compared both in the lower half of the seat back, the duty belt location and the upper half of the seat back, to estimate upper back support. The variables of interest were total pressure, calculated by adding the pressure readings from each active sensor in mmHg and the pressure area, calculated as a count of the number of active cells in each mat and then converted to cm^2.

5.3.5 Data Reduction

Previous work investigating simulated police driving has demonstrated significantly different postures during driving and typing tasks on an MDT (Gruevski et al., *in press*). As such, the driving and typing tasks in the current investigation were parsed out in each 15 minute block for all objective measures (interface pressures, accelerometers and kinematics) (Figure 14). The first and last 20 seconds were removed for the long duration tasks with a total of 560s typing and 260s of driving. In the intermittent tasks, the first and last 20 seconds of each driving task were removed and the first and last 10 seconds of each intermittent typing task were removed with40s of typing and 200s of driving for each of the three typing and driving tasks per block. These data sections were removed in order to remove any artefact from the transitions between driving and typing.

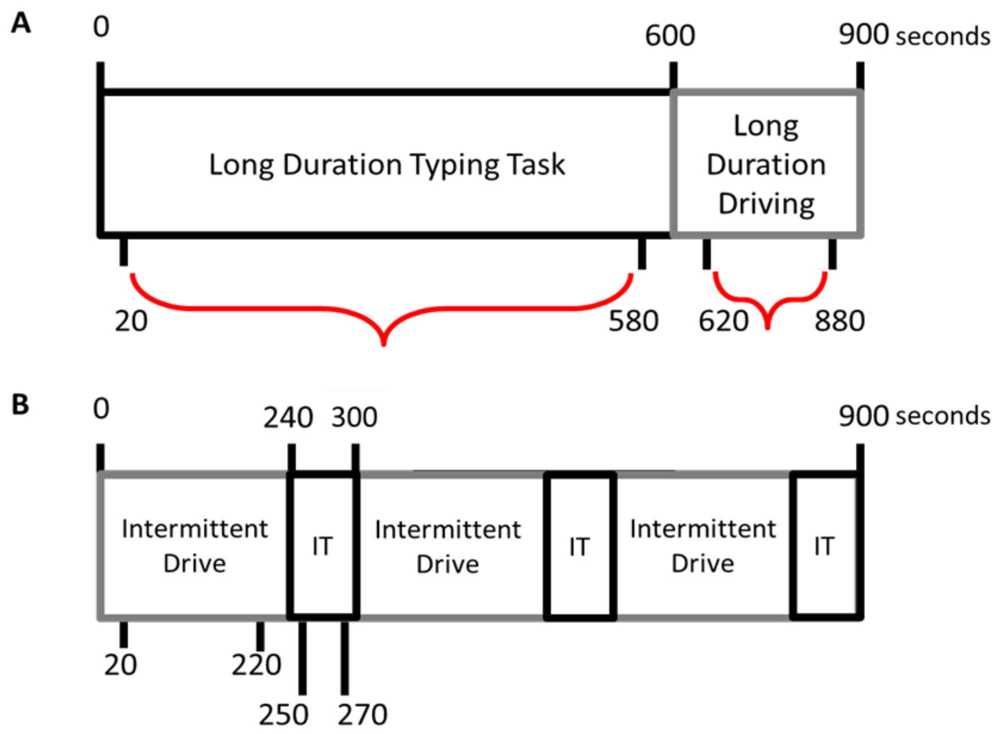


Figure 14 Schematic representing data reduction in the long duration conditions (A) and the intermittent conditions (B)

5.3.5 Discomfort

A custom made graphical user interface was generated using Matlab (v.7.11.0, R2010b, Natick, MA, USA) to display a 100mm visual analog scale to record ratings of perceived discomfort (RPD) (Figure 15). Ratings were collected for 13 body locations including, the neck, left and right shoulder, left and right upper middle and low back, left and right buttock and left and right thigh. A metric ruler was used to complete a sensitivity analysis and to adjust the size of the display prior to collection to ensure that the screen size corresponded to 100mm.

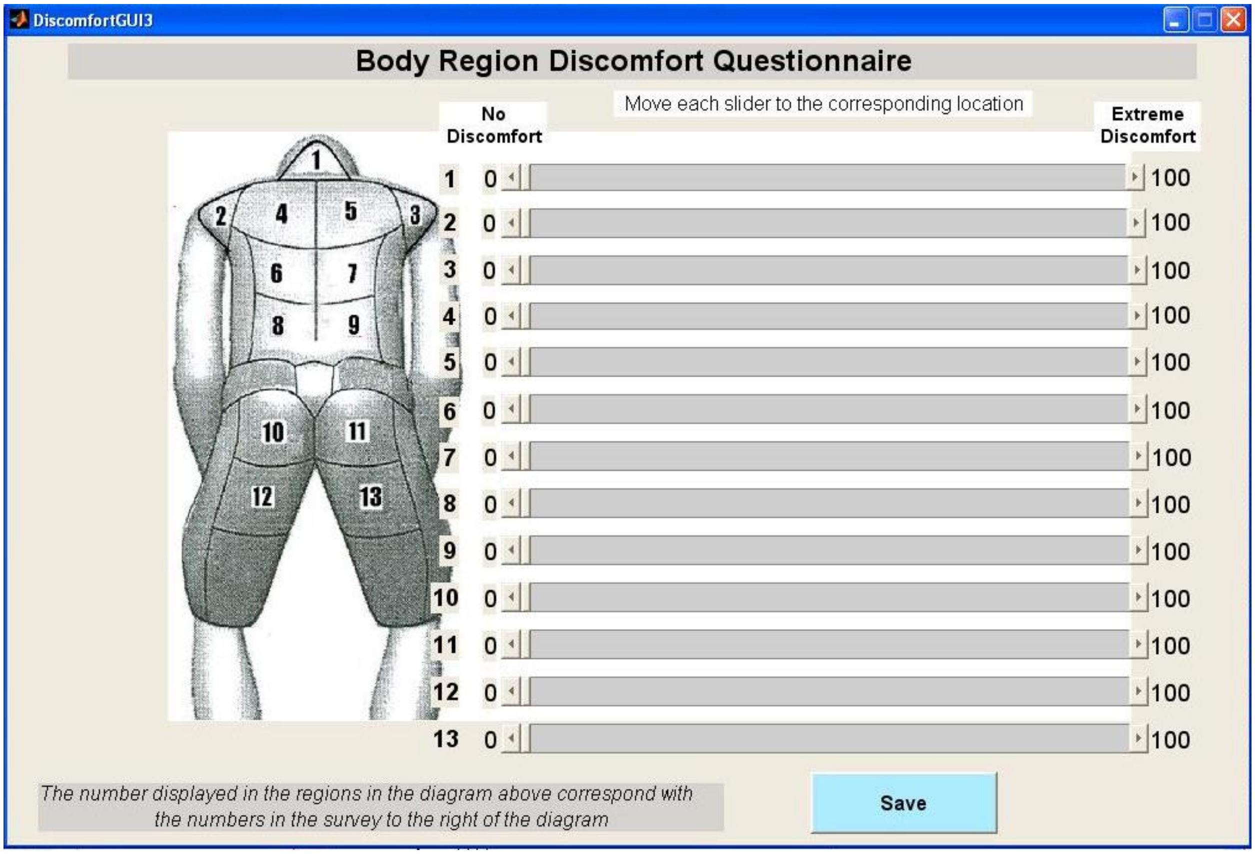


Figure 15 Screen capture of graphical user interface of discomfort survey

Surveys were completed following each 15 minute time block with the first RPD recorded at baseline prior to the driving simulation; a total of 9 RPD scores per session. The RPD was anchored on a scale from 0mm, representing "no discomfort" to 100mm representing "extreme discomfort." The baseline discomfort at the initiation of testing for each session was removed from all subsequent discomfort scores to isolate the discomfort response associated with the driving and MDT usage tasks.

5.3.6 Statistical Analysis

The objective measures (pressure, accelerometry, kinematics) were segmented into 4 distinct tasks; long duration typing, long duration driving (blocks 1 and 8), intermittent driving, and intermittent typing (blocks 2-7). Two four-way mixed general linear models with repeated measures on time, seat and task and a between factor of gender were completed on each group of tasks (SAS software, Version 8e for Windows, SAS Institute Inc., Cary, NC, USA). The long duration typing and driving tasks were compared (2 gender*2 time*2 task*2 seat condition) (Table 6).

Table 6 Long duration tasks independent and dependent variables

Independent variables	Dependent variables
Gender (male, female)	Pressure area seat back (top)
Seat (CV, TS)	Pressure area seat back (bottom)
Task (Typing, Driving)	Pressure area seat pan
Time (block1, block8)	Total pressure seat back (top)
	Total pressure seat back (bottom)
	Total pressure seat pan
	Lumbar angles (degrees)
	Lumbar angles (normalized, %)
	Pelvic angles (degrees)
	Pelvic angles (normalized, %)
	Neck flexion angles
	Neck axial rotation angles
	Thoracic axial rotation angles

Comparisons were made between the intermittent typing and driving tasks (2 gender*6 time*2 task*2 seat condition) (Table 7). Tukey's post hoc was used to examine significant time effects and interactions. Statistical significance was set at α=.05.

Table 7 Intermittent tasks independent and dependent variables

Independent variables	Dependent variables
Gender (male, female)	Pressure area seat back (top)
Seat (CV, TS)	Pressure area seat back (bottom)
Task (Driving Task1, Typing Task1, Driving Task2, Typing Task2, Driving Task3, Typing Task3)	Pressure area seat pan
Time (block2, block3, block4, block5, block6, block7)	Total pressure seat back (top)
	Total pressure seat back (bottom)
	Total pressure seat pan
	Lumbar angles (degrees)
	Lumbar angles (normalized, %)
	Pelvic angles (degrees)
	Pelvic angles (normalized, %)
	Neck flexion angles
	Neck axial rotation angles
	Thoracic axial rotation angles

Discomfort was analyzed both based on peak discomfort and changes over the course of the simulation. A three way mixed general linear model (2 gender*8 time*2 seat condition) with repeated measures on seat and time was applied to discomfort scores. Prior to statistical testing, Mauchly's test was applied to the data to test if the assumption of sphericity was met. If the assumption was not met, the adjusted p value from the Huynh-Feldt analysis was reported. A two way mixed general linear model (2 gender*2 seat condition) was applied to the peak discomfort in each body location regardless of time point. Planned pairwise comparisons were completed to examine significant time effects. Statistical significance was set at α=.05.

CHAPTER 6.0 Results

To reflect the statistical approach employed, data from the long duration and intermittent tasks are presented separately for the objective measures.

6.1 Discomfort

Average discomfort scores were low with all values remaining below 10mm. Discomfort was found to increase over the simulation duration regardless of backrest condition in six body locations (Table 8). A significant ($p=0.0016$) time by seat interaction was found where the thoracic support elicited lower neck discomfort scores early in the simulation, and the TS exhibited an increased discomfort compared to the standard CV seat over the final 30 minutes of the simulation (Figure 16). There was a significant ($p= 0.0473$) increase in average discomfort of 1.6mm in the right thigh for the thoracic support condition. There was no effect of gender on the average discomfort.

Table 8 Average discomfort over time across seat condition and gender. P values less than 0.05 are significant, with (*) indicating significant differences from time block 1

Body Location	Time (minutes)								P-value
	15	30	45	60	75	90	105	120	
Left Shoulder	0.9 (2.2)	0.5 (1.3)	0.8 (1.7)	1.2 (1.8)	1.3 (1.9)	1.5 (2.1)	1.3 (1.9)	1.8 (2.9)	0.1123
Right Shoulder	0.6 (1.6)	0.8 (1.5)	0.9 (1.7)	1.5 (2.1)	1.3 (2.2)	1.5 (2.2)	1.5 (2.1)	2.1(3.0)*	0.0421
Left Upper Back	0.3 (1.0)	0.3 (1.0)	0.4 (1.5)	0.5 (1.8)	0.6 (2.0)	0.9 (2.5)	0.8 (2.5)	1.3 (3.7)	0.2407
Right Upper Back	0.3 (0.9)	0.2 (0.7)	0.5 (1.7)	0.7 (2.3)	1.0 (2.8)	1.0 (3.0)	1.0 (3.0)	1.7 (4.5)	0.1932
Left Mid Back	0.1 (0.4)	-0.7 (4.8)	-0.5 (4.8)	0.0 (5.3)	-0.3 (5.0)	0.5 (6.0)	1.0 (6.1)	1.7 (7.0)	0.1132
Right Mid Back	0.3 (1.4)	-0.5 (5.2)*	-0.2 (5.3)*	1.9 (7.5)	1.8 (7.3)	2.4 (7.8)	2.3 (7.6)	3.6 (8.9)	0.0403
Left Low Back	1.0 (2.2)	1.9 (3.0)	1.8 (2.6)	2.7 (3.6)*	3.6 (4.3)*	4.9 (7.0)*	5.0 (6.6)*	6.5 (8.4)*	0.0088
Right Low Back	1.3 (2.3)	3.2 (3.9)*	3.9 (3.7)*	4.3 (4.8)*	6.2 (6.6)*	7.1 (8.5)*	7.3 (7.4)*	9.5 (9.6)*	0.0037
Left Buttock	0.5 (1.6)	0.2 (1.4)	0.7 (2.0)	0.6 (2.1)	1.3 (2.9)	1.3 (2.9)	1.6 (3.4)	1.7 (3.8)	0.0327
Right Buttock	0.6 (1.5)	0.9 (2.8)	1.3 (3.0)	1.3 (3.3)	2.2 (4.5)	1.7 (3.9)	2.9 (5.0)*	2.9 (5.4)*	0.0082
Left Thigh	0.2 (0.8)	0.1 (0.4)	0.3 (1.1)	0.3 (1.2)	0.4 (1.5)	0.7 (2.0)	0.9 (2.4)	0.8 (2.2)	0.1502
Right Thigh	0.5 (1.5)	0.6 (1.9)	0.5 (1.4)	0.8 (1.8)*	1.3 (2.7)	1.3 (2.7)	2.6 (4.8)*	2.7 (4.8)*	0.0219

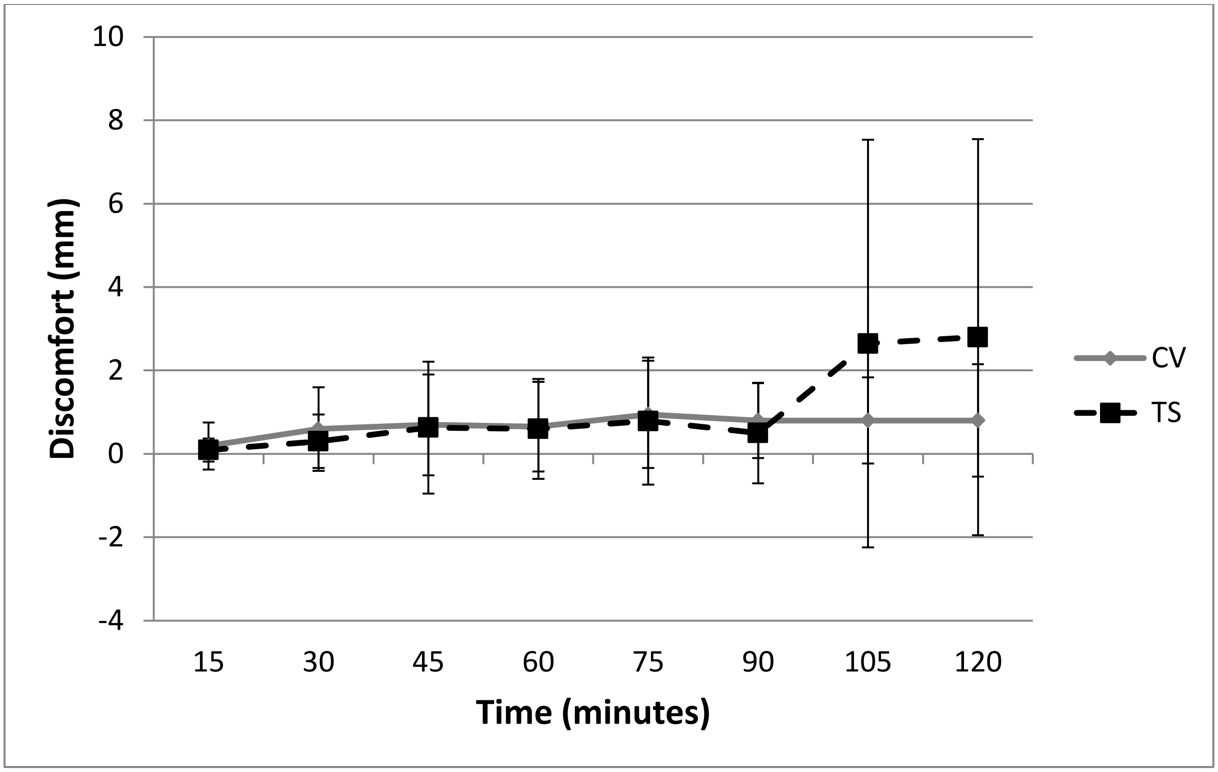


Figure 16 Mean neck discomfort by seating condition over time.

The peak discomfort per body location was examined to determine if the thoracic condition lessened the maximum discomfort developed compared to the standard seat. The thoracic condition elicited mean decreases in discomfort in the left mid back that trended toward statistical significance (p=0.071). A Cohen's d effect size (Ellis, 2010) was calculated on mid back peak discomfort according to equation 1, and demonstrated a moderate effect size at d=0.5.

Equation 1. (Ellis, 2010)

$$Cohen's\ d = \sqrt{\frac{Mean1 - Mean2}{\left(\frac{\sum(Value\ n1 - Mean1)^2 + \sum(Value\ n2 - Mean2)^2}{(group\ size1 - group\ size2) - 2}\right)}}$$

6.2 Pressure Measures

6.2.1 Long Duration Tasks

The seat pan total pressure increased over time and interacted with gender, task and seat while no change was elicited in seat back total pressure. There was an average increase of 4579 mmHg in the total pressure on the seat pan over time comparing the first and last blocks of time (p=0.0304) (Figure 17). There was a significant task by seat by gender interaction in the seat pan total pressure (p= 0.0459). The long duration driving and typing tasks are plotted separately in Figure 18, but total pressure changes were affected in the same way in each task. The total pressure on the seat pan was found to decrease with the thoracic support in males, but was found to increase in females compared to the standard CV seat. There was no main effect of gender, seat or time on the total pressure on the seat back.

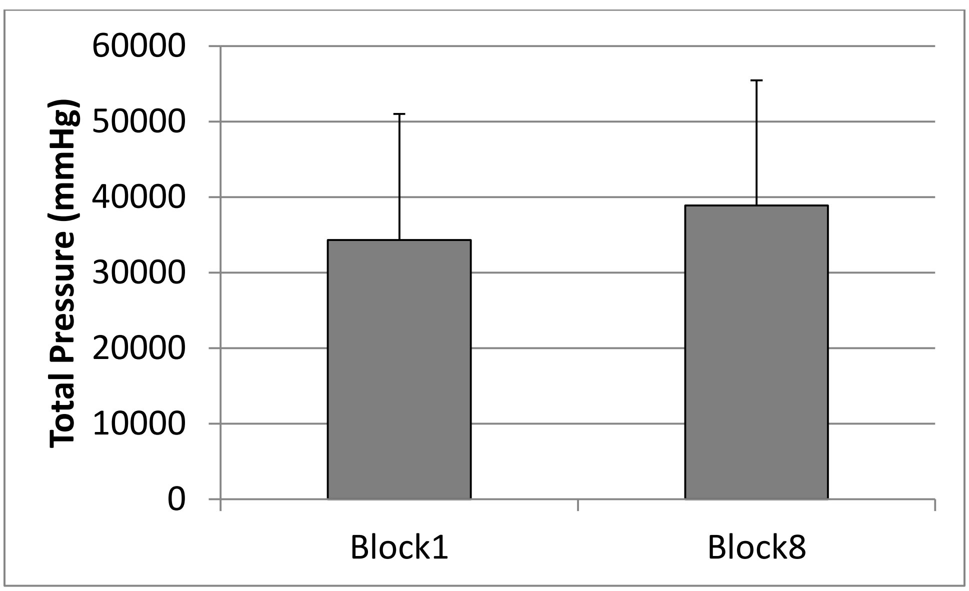
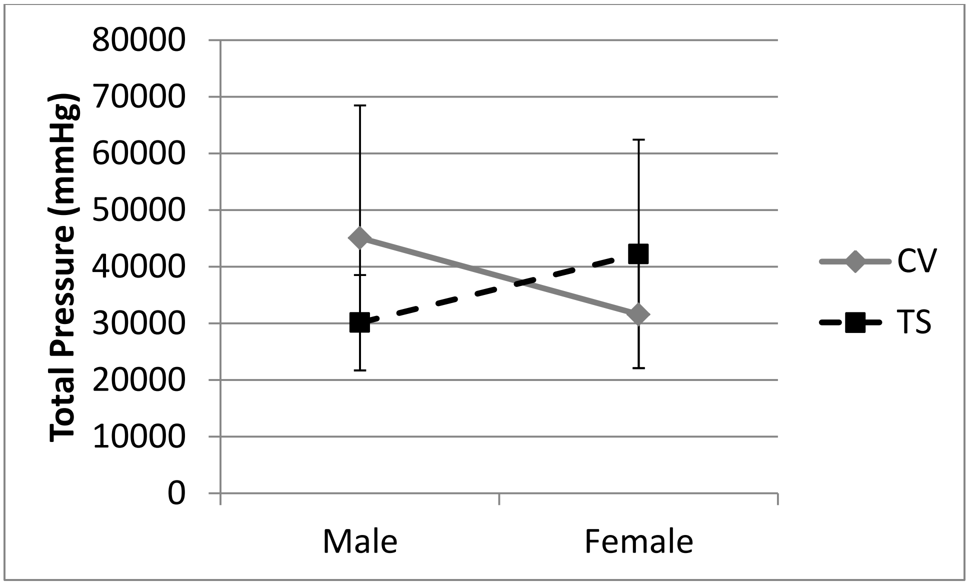
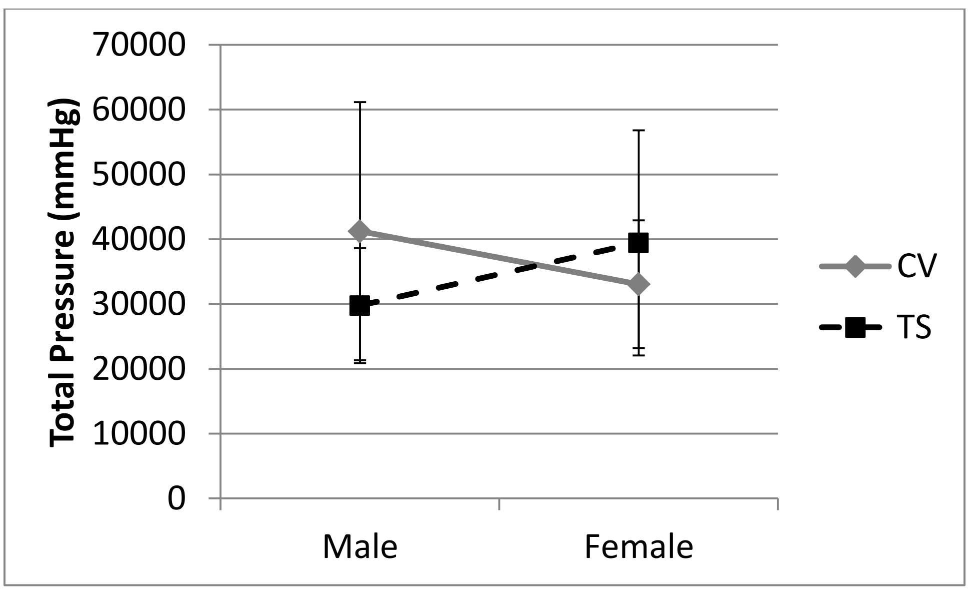


Figure 17 Seat pan total pressure increased from the first time block compared to the last time block



(A)



(B)

Figure 18 Seat pan total pressure by gender and seating condition during driving tasks (A) and typing tasks (B)

There were no significant effects of seat, gender or time on the pressure area in the seat pan. In the seat back, the pressure area increased in the top half of the seat back with the support and decreased in the bottom half of the seat back. There was a significant seat by task interaction (p=0.0074) in the lower half of the seat back where the thoracic support had a greater impact on reducing pressure area during the driving task than during the typing task (Figure 19).

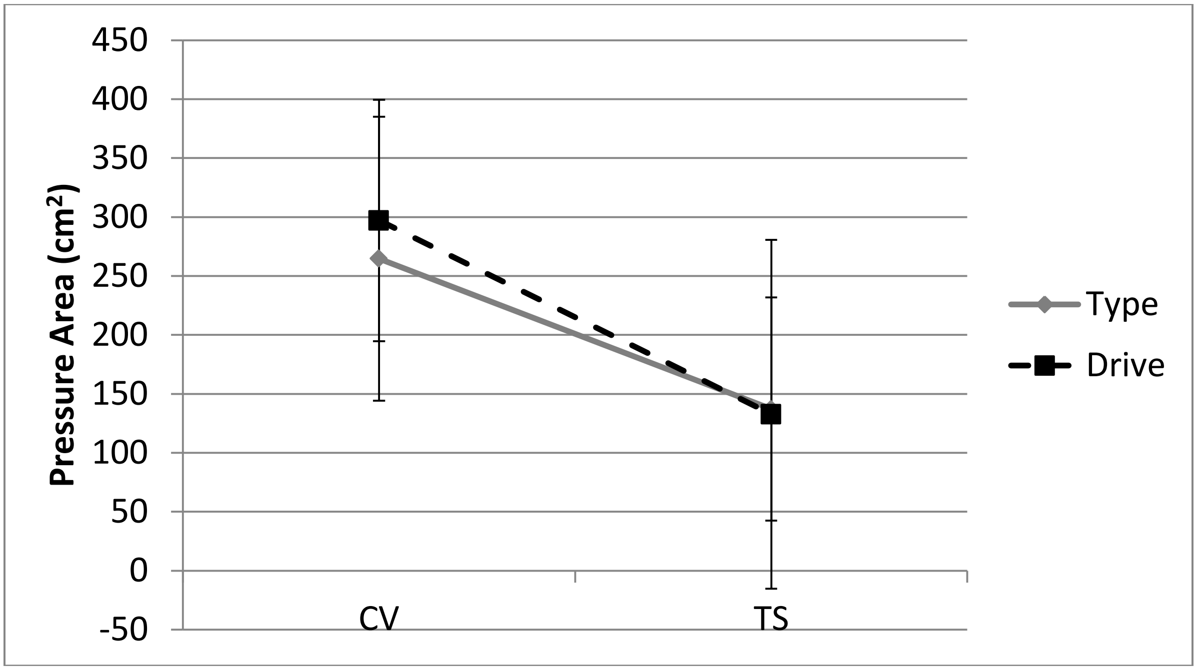
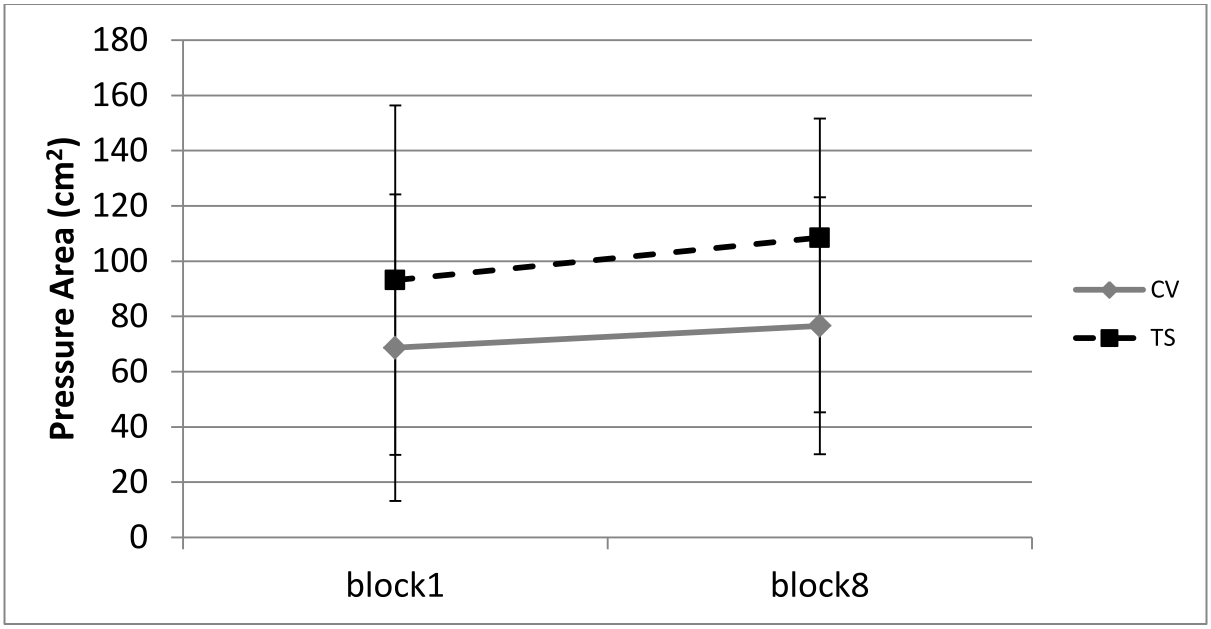
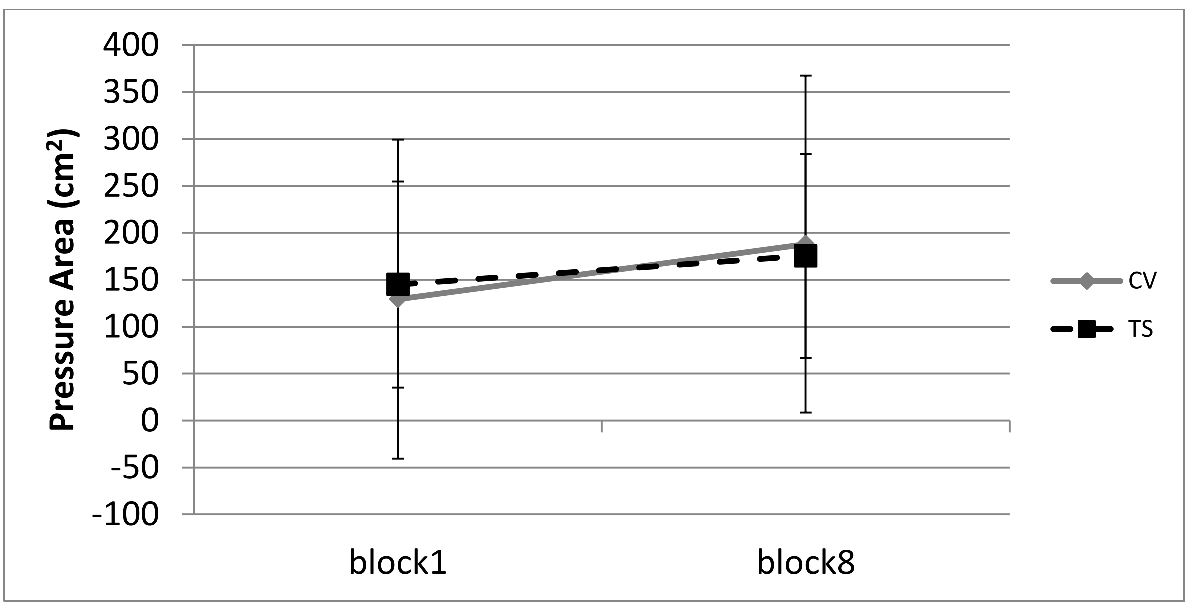


Figure 19 Lower seat back pressure area is reduced in the thoracic support condition for both driving and typing tasks across gender

There was a significant (p=0.0299) time by seat by task interaction (Figure 20) in the upper half of the seat back. The upper seatback pressure area was higher in the thoracic condition during driving compared to the standard seating condition, but pressure values were similar during the typing task. In driving, the pressure area in the TS condition had a more rapid increase over time compared to the CV. The opposite pattern occurred in the typing condition; where the CV seating condition had a more rapid increase.



(A)



(B)

Figure 20 Upper seat back pressure area during driving (A) and typing (B) tasks

6.2.2 Intermittent Tasks

The total pressure on the seat pan during the intermittent driving tasks was found to increase over time (p=0.0205). There was no significant effect of gender or seat on the seat pan total pressure. When the seat back pressure profile was divided into upper and lower blocks, the lower half of the seat back demonstrated a significant main effect of seat (p=0.0324) where total pressure was reduced in the thoracic condition (Figure 21).

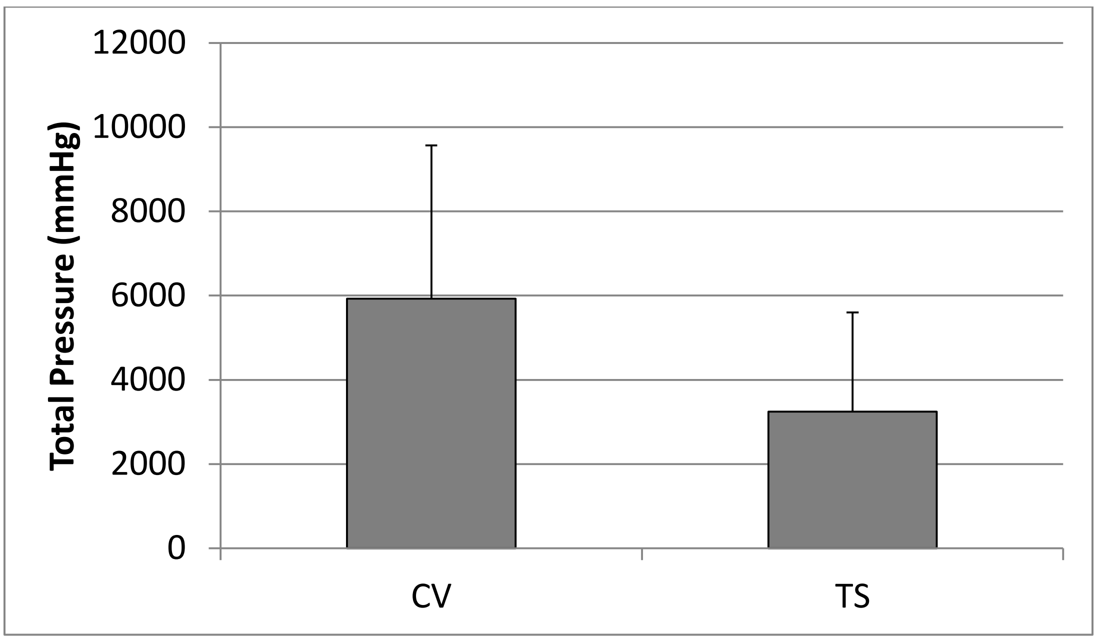


Figure 21 Total Pressure on the lower half of the seat back is reduced in the thoracic condition for the intermittent typing task

There was no main effect of gender, seat or time on the pressure area on the seat pan during the intermittent tasks. There was no effect of gender on the pressure area on the seat back. In the upper part of the seat back, there was no effect of seat, but there was a significant time by task interaction (p=0.0023). In the lower half of the seat back, there was no significant effect of time, but there was a significant main effect of seat (p=0.0008) where average pressure area on the lower half of the seat back was reduced in the thoracic condition compared to the standard seat (Figure 22).

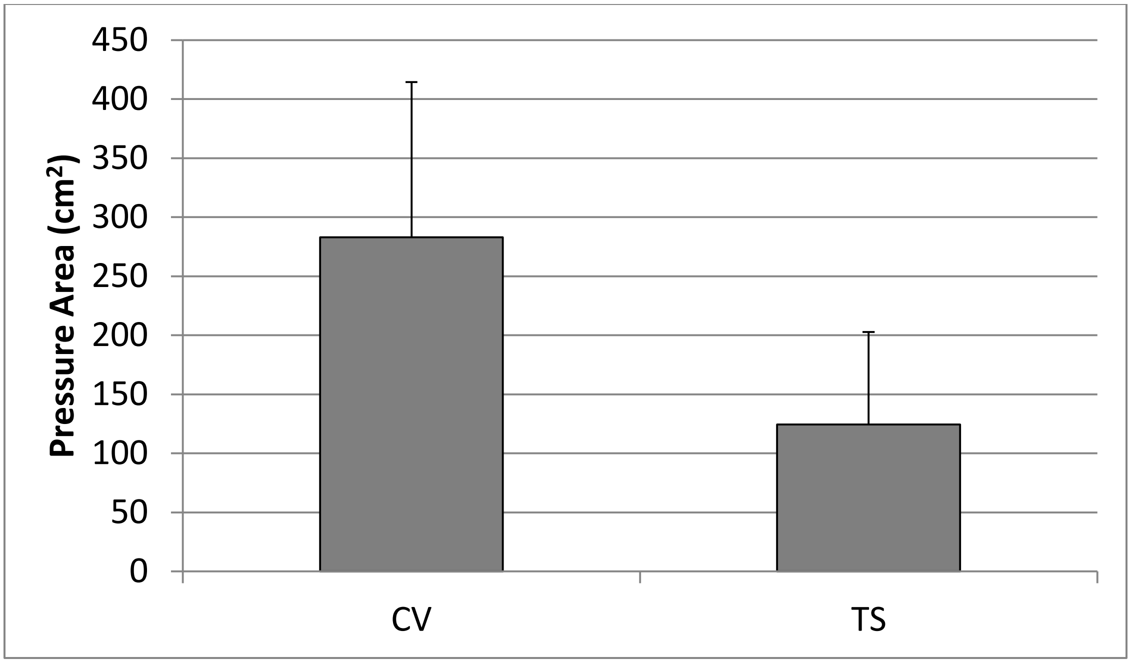


Figure 22 Pressure area on the lower half of the seat back is reduced with the thoracic support

6.3 Lumbar Spine Postures

6.3.1 Long Duration Tasks

Lumbar angles are presented as percentages of functional range of motion with 0 percent representing standing postures and 100 percent representing maximum flexion. There were no significant interactions of seat, gender, time or task. There was a main effect of seating condition (0.0069) (Figure 23). The lumbar angles in the CV condition are closer to standing values, whereas the postures in the TS condition represent increased lumbar flexion. There was no main effect of gender or time on lumbar angles during the long duration tasks.

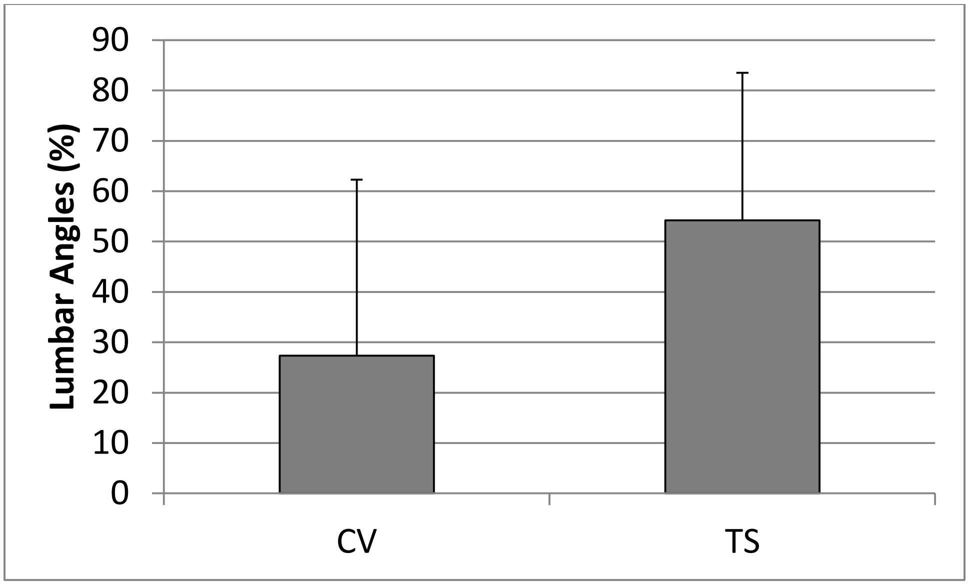


Figure 23 Normalized lumbar angles by seating condition

Pelvic angles are presented as angles that deviate from the vertical with negative values representing posterior pelvic inclinations and positive values representing anterior pelvic inclinations. There was a significant gender by seat interaction (p=0.0393) where women had a greater reduction in posterior pelvic rotation with the TS while males had greater posterior pelvic rotation with the support (Figure 24). There was a significant time by task interaction (p=0.0214) in pelvic angles during the long duration tasks where posterior pelvic rotation increased over time during the typing tasks but decreased overtime in driving (Figure 25).

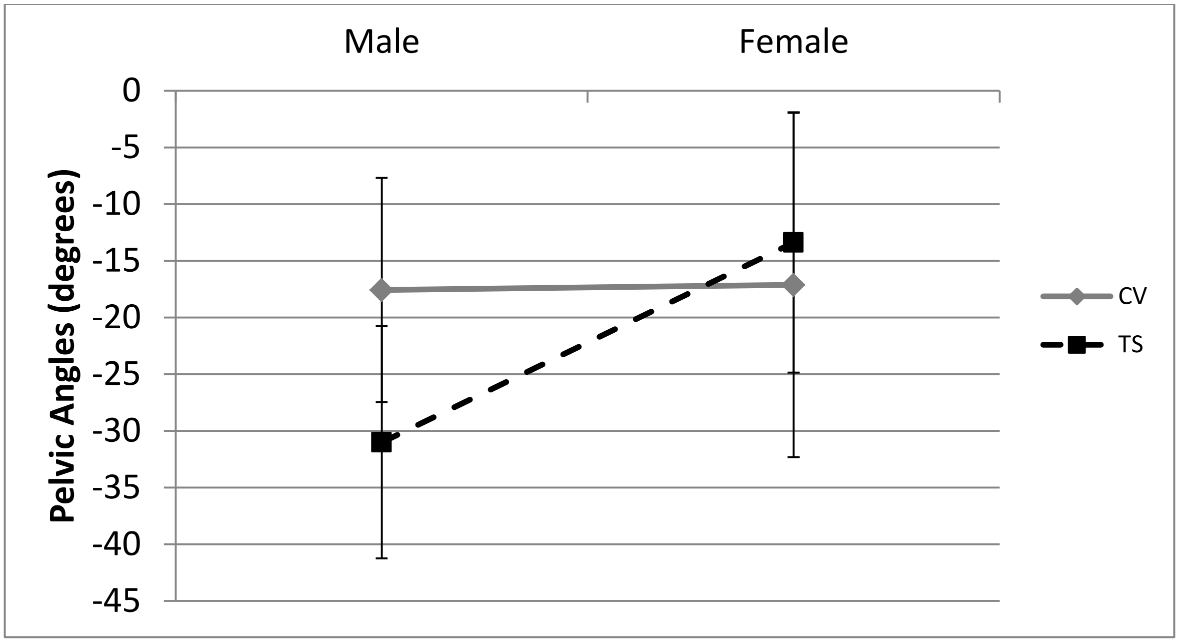


Figure 24 Pelvic angles by seating condition and gender

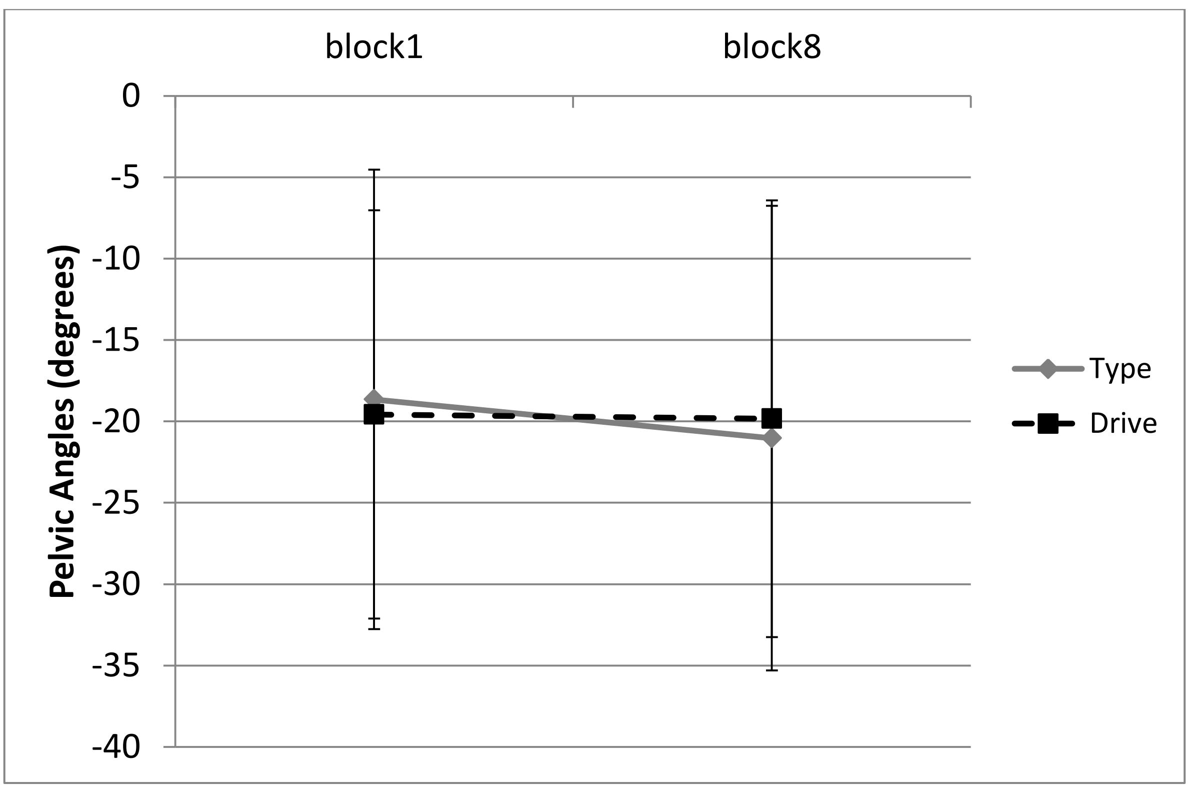


Figure 25 Pelvic inclination angles by time and task

6.3.2 Intermittent Tasks

Using the thoracic support resulted in significantly more flexed postures compared to the standard CV seat (p=0.0118) (Figure 26). There was a significant main effect of time (p<0.0001) on normalized lumbar angles where lumbar flexion decreased by an average of 6.7 percent from time block 2 to time block 7 (Figure 27). There was also a significant task by gender interaction where male participants had greater lumbar flexion during the typing task than female participants, but flexion angles were similar during the driving tasks (p=0.0055) (Figure 28).

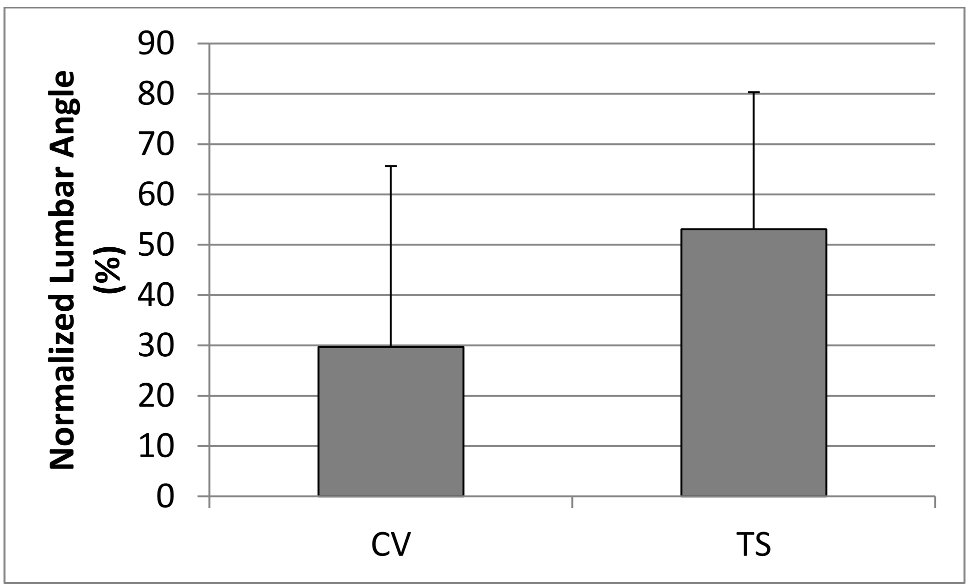


Figure 26 Normalized lumbar angles by seating condition

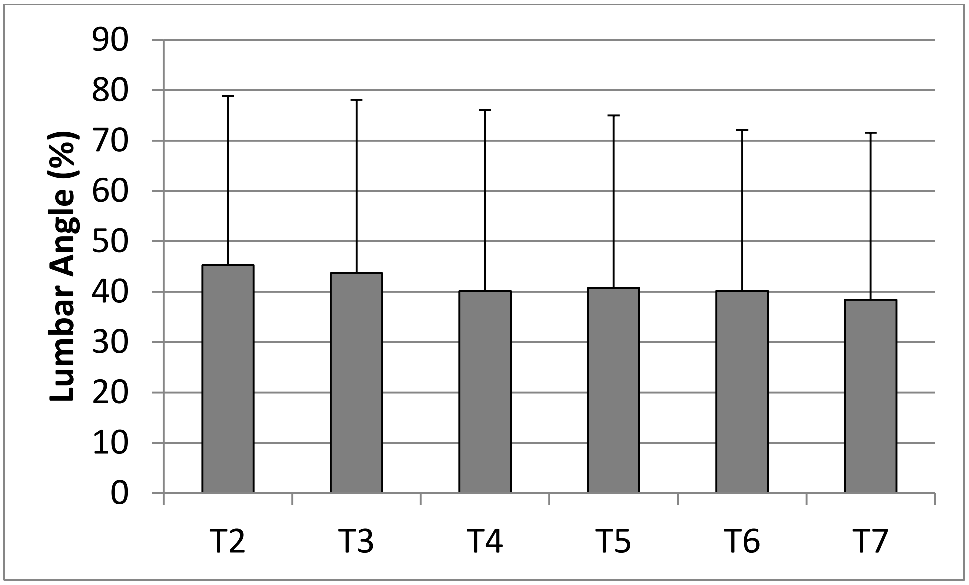


Figure 27 Normalized lumbar flexion angles by time during the intermittent tasks

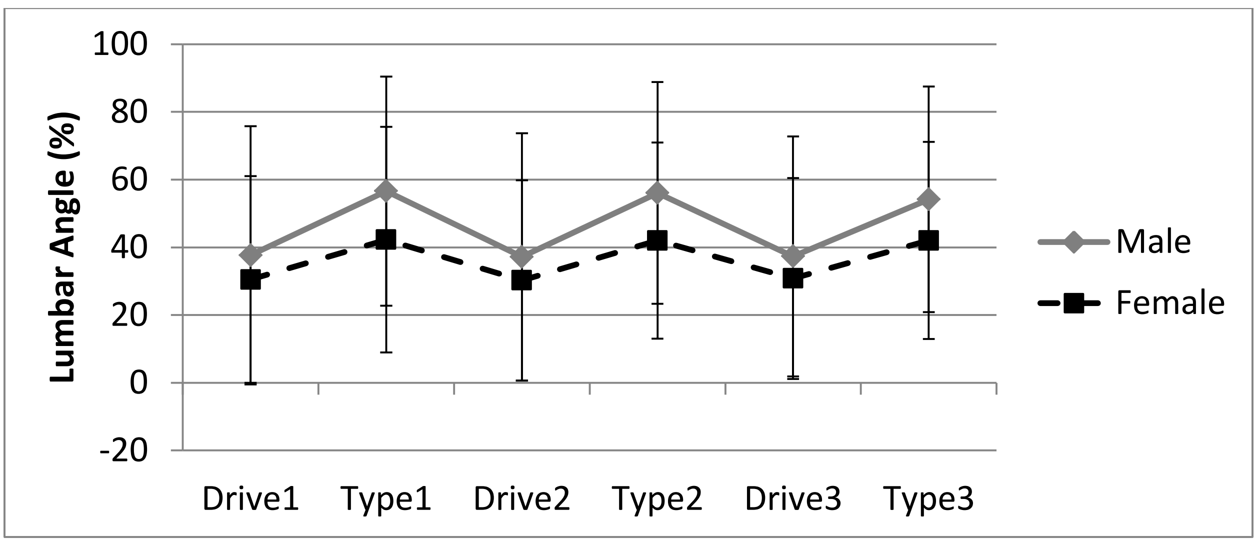


Figure 28 Normalized lumbar angles during the intermittent blocks by gender and task

In pelvic angles, there was no significant main effect of time. There was a significant (0.0455) gender by seat interaction where there was a reduction in posterior pelvic rotation in women during the thoracic seating condition and greater posterior pelvic rotation in males in the thoracic condition (Figure 29).

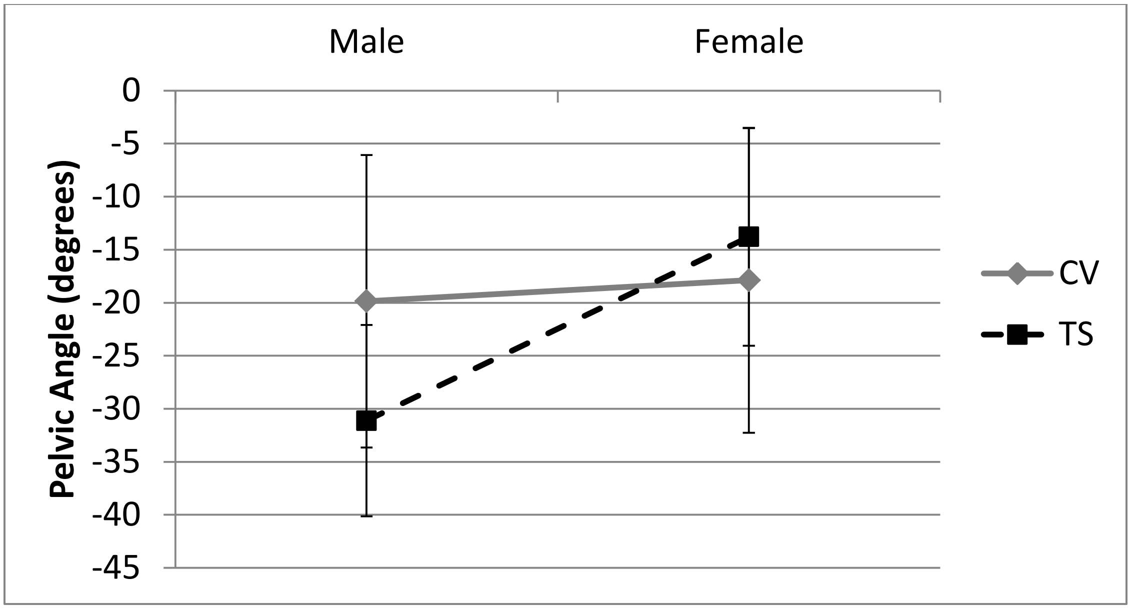
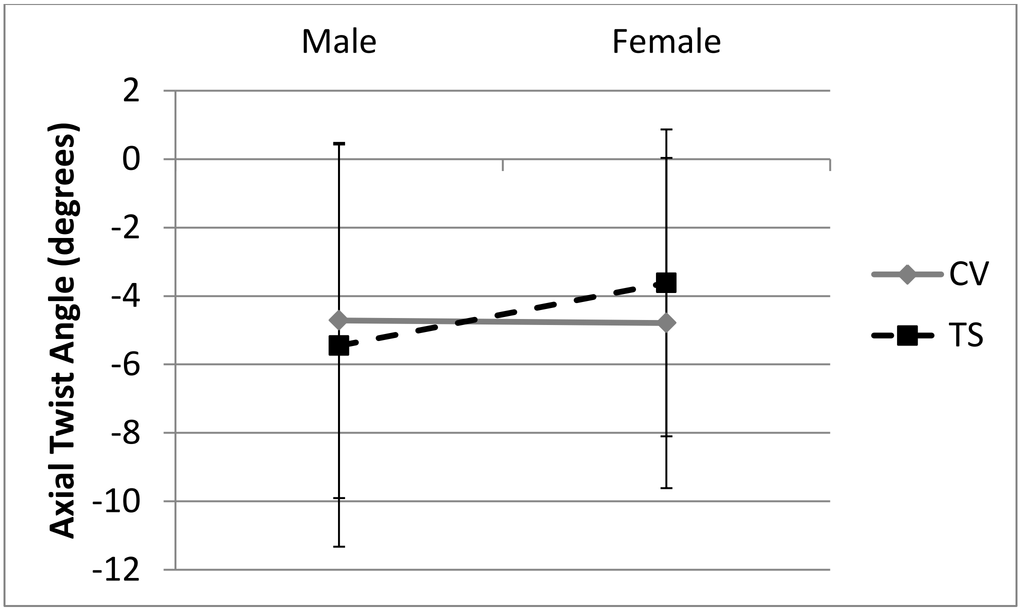


Figure 29 Pelvic angles by seating condition and gender

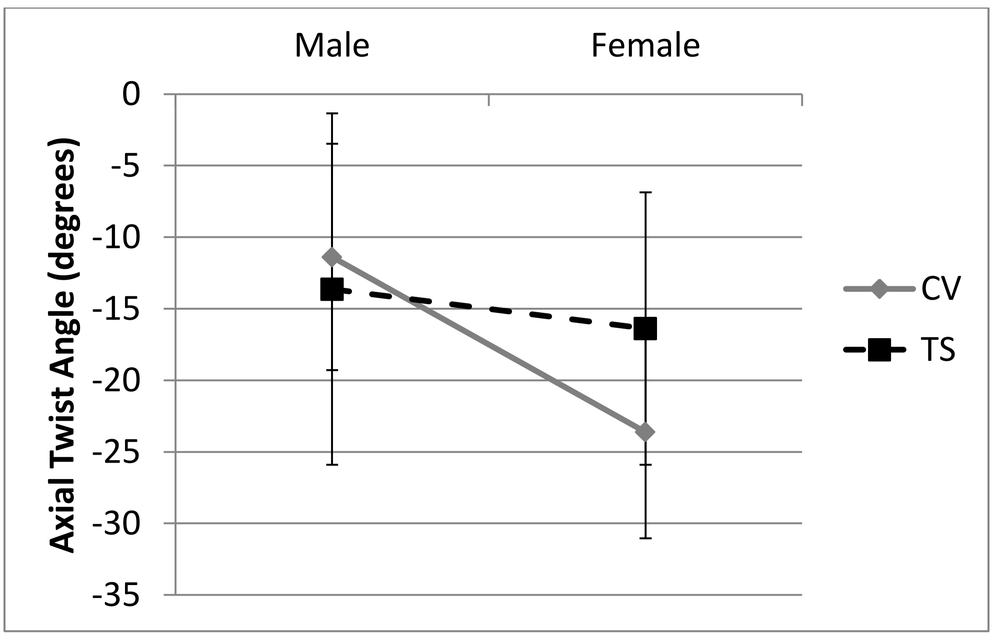
6.4 Trunk and Neck Kinematics

6.4.1 Long Duration Tasks

Trunk axial rotation was calculated as torso rotation with respect to the pelvis with the whole trunk modelled as a rigid segment. There was a significant task by gender by seat interaction in the axial rotation of the trunk ($p = 0.0271$) (Figure 30). The thoracic support mitigated axial trunk rotation in female participants by an average of 7.2 degrees and increased rotation by an average of 2.3 degrees in males during the typing tasks. Graphs of the responses are plotted separately for the different tasks (Figure 30). There was no effect of seat type on neck postures.



(A)



(B)

Figure 30 Axial rotation of the trunk by seating condition and gender for driving (A) and typing (B) tasks with negative values representing right trunk axial rotation relative to the pelvis

6.3.2 Intermittent Tasks

There was no effect of time, gender or seat on the axial rotation of the trunk during the intermittent tasks. Neck angles are presented as the flexion and extension of the head segment with respect to the torso segment with positive values representing flexion and negative values representing extension. There was a significant seat by gender interaction in neck angles (p=0.0311) where there was greater neck extension in males with the thoracic support compared to the standard seat across both typing and driving (Figure 31).

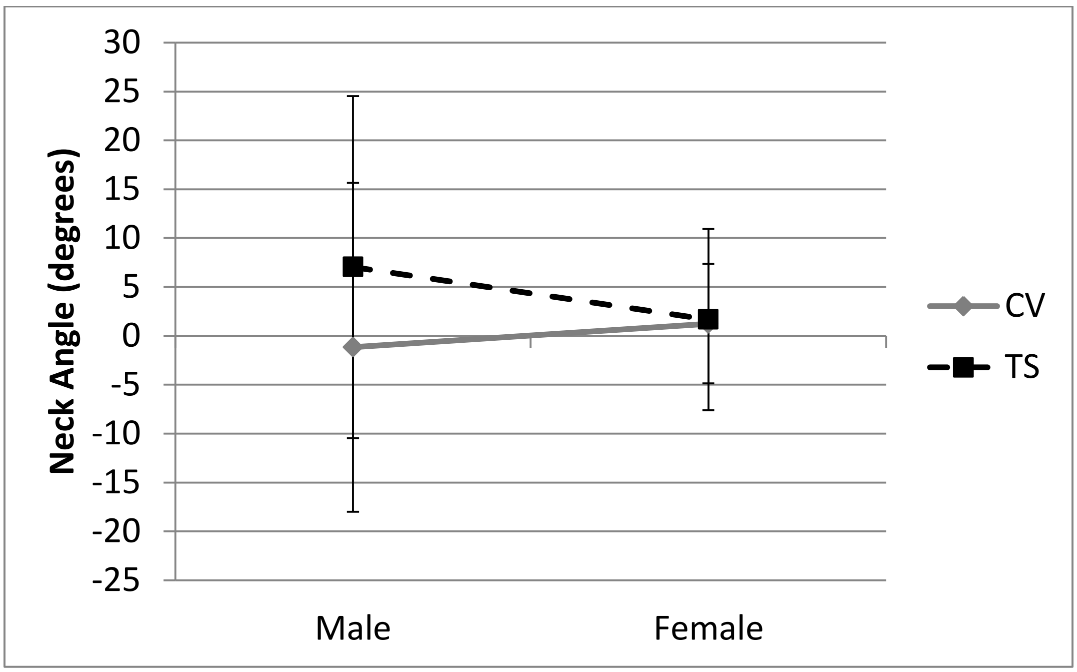


Figure 31 Neck angles by gender and seating condition. Negative values represent neck flexion

CHAPTER 7.0 Discussion

A prototype thoracic support was built and tested using lab simulated driving and typing tasks in order to replicate the activities of officers and evaluate the prototype. This evaluation was completed to test four hypotheses; 1) The seating intervention will increase the amount of lumbar lordosis compared to a standard seat and gender will not have an effect on lumbar angles; 2) with the thoracic support, seat back interface pressures will be higher and seat pan pressures will be lower compared to a standard seat and gender will not have a direct effect on interface pressures; 3) discomfort will be lower in the intervention condition and will not depend on gender; 4) lumbar postures will become more flexed, interface pressures will increase and discomfort scores will increase over the course of the simulation.

Based on the results of the investigation, the first hypothesis can be rejected for both lumbar angles and pelvic inclinations. Male participants were found to have greater lumbar flexion than female participants during the typing tasks with reduced lumbar flexion during driving tasks. The thoracic support was found to increase lumbar flexion angles compared to the Crown Victoria Interceptor seat. This increase in flexion in normalized angles is relative to an extended (standing) lumbar angle. The amount of flexion produced in the TS condition is still within a healthy range of motion of spine postures as the lumbar angles present during the thoracic support condition in this study were similar to previous work involving prolonged non-occupational driving (De Carvalho et al., 2011). However, prolonged driving without on-person equipment is also potentially linked to discomfort (Chen et al., 2005; Alperovitch-Najenson et al., 2010). While the TS condition elicited postures similar to non-occupational driving, this may not remove the potential for discomfort reporting.

The present study found averaged normalized lumbar flexion angles of 54.2 (29.3)% in the long duration tasks and 53.1 (27.2)% during the intermittent tasks compared to 50 (1.5)% and 60 (1.27)% for men and women respectively during the second hour of simulated driving in De Carvalho et al. (2011). The postures assumed with the thoracic support produced postures more similar non-occupational driving than the CV condition in the present study, that resulted in average lumbar flexion postures of 27.3 (34.9)% during long duration blocks and an average of 29.7(36.0)% during the intermittent blocks. While postures in the CV were found to be closer to upright standing values, this may not represent postures that reduce discomfort reporting (De Carvalho and Callaghan, 2011b). A recent investigation conducted by Holmes et al. (*submitted*) compared lumbar postures between a standard duty belt configuration and a modified configuration removing items on the belt from the low back area. Normalized lumbar postures were found on average to have greater flexion in the reduced belt compared to the standard belt with 34.5(29.9)% and 27.5(27.8)% respectively, similar to the trend found in this study of increasing lumbar flexion. A recent investigation examining lumbar supports in vehicle seats demonstrated increased lumbar lordosis with a lumbar support compared to no support, however there was no change noted in pelvic postures (De Carvalho and Callaghan, 2012). This increase in lordosis with a fixed pelvis has been shown to increase discomfort reporting (De Cravalho and Callaghan, 2011b) hypothesized to be due to the increased tension at the lumbosacral junction (De Carvalho and Callaghan, 2012). This suggests that discomfort scores increased despite postures closer to standing values while sitting (De Carvalho and Callaghan, 2011b). Previous work has documented an increased lumbar lordosis with the use of a lumbar support in vehicle seating (De Carvalho and Callaghan, 2012; Reed and Schneider, 1996; Andersson et al., 1974). However, these studies did not involve the use of on person occupational equipment.

In the present study, a gender difference was found in pelvic inclination angles where males had greater posterior pelvic inclinations with the support while females had a reduction in posterior pelvic inclinations with the thoracic support. This result was surprising as the reverse effect was seen in previous work where women were found to have greater posterior pelvic inclinations in the ALS seat and males were found to have more anterior pelvic rotations in the ALS seat (Holmes et al., *submitted*). However, the magnitudes were generally small with 9.7 (7.4) degrees and 11.7 (6.5) degrees of posterior pelvic inclinations with respect to the vertical for men and women respectively (Holmes et al., *submitted*). The current investigation found posterior pelvic inclinations with respect to the vertical of 31.0 (10.2) degrees and 13.4 (11.5) degrees for men and women respectively. Previous work in office seating has demonstrated gender differences in pelvic postures where women sit with more anterior rotation of the pelvis than males (Dunk et al., 2005). This has also been demonstrated in occupational simulated driving (Gruevski et al., *in press*).

The second hypothesis can be accepted for pressure area and partially accepted for total pressure. The seat pan total pressure was found to decrease with the thoracic support in males, but increase in females. Total pressure and pressure area were both found to decrease in the lower half of the seat back with the thoracic support compared to a CV seat. The lower half of the seat is the location of the equipment of the duty belt. The duty belt, the side arm, radio and the body armour were the articles of equipment rated as causing the highest perceived discomfort by surveyed officers (Donnelly et al., 2009). The results of the present investigation demonstrate less contact area as measured by total pressure in the area where high discomfort has been reported (Donnelly et al., 2009) in police officers. This reduction in interface pressure with the intervention has the potential to reduce discomfort reporting in officers compared to a standard vehicle package.

The discomfort findings in the current investigation partially supported the third hypothesis. There was no significant effect of gender on discomfort scores. However, there was a significant increase in discomfort in the right thigh and a significant seat by time interaction where discomfort in the neck increased later in the simulation during the thoracic condition. This was surprising as previous studies involving lumbar supports have shown reductions in discomfort (De Looze et al., 2003; Donnelly et al., 2009). Average discomfort scores were found to be low with all values below 10mm. Previous work examining low back pain and driving point to a cumulative exposure to driving to increase low back pain (Porter and Gyi, 2002). Participants who completed work related-driving for over 20 hours per week had six times higher incidences of low back pain than those who drove for under 10 hours per week (Porter and Gyi, 2002). Despite the increases in discomfort during the thoracic condition in the present investigation, average discomfort values in the control seating condition were also low and comparable to previous work investigating prolonged occupational driving (Holmes et al., *submitted*). During the intermittent blocks, participants were cued every 4 minutes with an auditory tone to type for 1 minute. There is evidence to suggest that distraction can reduce perceived pain (Eccleston and Crombez, 1999). Further, it is possible that continuous sitting (without MDT usage) is needed for discomfort to develop.

The interface pressure and discomfort data support the fourth hypothesis while the lumbar angles do not. Normalized lumbar flexion angles were found to decrease by an average of 6.8 percent comparing block 2 to block 7 during the intermittent tasks. There was no statistically significant difference in lumbar flexion angles during the long duration tasks. These findings differed from previous work that has shown increases in lumbar flexion in automotive seating (Callaghan et al., 2010). This suggests that perhaps the increased movements during the intermittent typing tasks prevented viscoelastic creep of the biological tissues in the back that have been hypothesized as a factor leading to increased trunk flexion over time during prolonged simulated driving exposures (Callaghan et al., 2010). Seat pan total pressure increased over time. This is consistent with previous work (Callaghan et al., 2010). Low back discomfort scores were found to increase over the course of the simulated exposure, which is consistent with previous work (De Carvalho et al., 2011; Callaghan et al., 2010; Gruevski et al., *in press*). A summary of the results relevant to the intervention and their interpretation are depicted in Table 9.

Table 9 Thoracic intervention significant results summary

Dependent Variable	Task	Result	Interpretation	Implications for TS
Averaged peak discomfort	all	↑ in neck region	All values below clinical significance criteria of 9 mm (Kelly, 1998).	Neutral
Pressure area seat back (top)	Long duration	↑ with TS	Interface pressure results suggest increased support in the upper half of the seat back and reduced pressure on the lower half of the seat back	Positive
	Intermittent	No effect of TS		
Pressure area seat back (bottom)	Long duration	↓with TS		
	Intermittent	↓ with TS		
Pressure area seat pan	Long duration	No effect of TS		
	Intermittent	No effect of TS		
Total pressure seat back (top)	Long duration	No effect of TS		
	Intermittent	No effect of TS		
Total pressure seat back (bottom)	Long duration	No effect of TS		
	Intermittent	↓ with TS		
Total pressure seat pan	Long duration	With TS, ↓ in males, ↑ in females		
	Intermittent	No effect of TS		
Lumbar angles (normalized, %)	Long duration	↑ flexion with TS	Despite increased normalized lumbar flexion with TS, lumbar postures are still within a neutral range of motion	Positive with reservations
	Intermittent	↑ flexion with TS		
Pelvic angles (degrees)	Long duration	With TS, ↑ posterior pelvic rotation in males, ↓ in females	Despite increased posterior pelvic rotation, TS allows for greater range of motion in pelvic postures	Negative
	Intermittent	With TS, ↑ posterior pelvic rotation in males, ↓ in females		

There were several limitations associated with this investigation. All participants were collected from a University population. It was assumed that postures of students during the simulation would replicate the postures assumed by on duty mobile police officers during patrol. Police officer hiring practices do not mandate height and weight restrictions; therefore it is reasonable to assume that students are anatomically representative of a police population. A future direction would be to test the support on officers. The dimensions of the simulator were designed to replicate the interior of the Ford Crown Victoria Interceptor. It was assumed that the simulator represents the vehicle. The simulator is without doors and a roof and is not equipped with a seat belt, making it less constrained than an actual vehicle. However, a laboratory setting allowed for more control and more involved instrumentation. The study was limited in that only one prototype support design was tested. However, the prototype tested in the present investigation was designed to replicate the ALS seat as it has been shown to successfully reduce discomfort (Donnelley et al., 2009).

CHAPTER 8.0 Conclusions

A prototype thoracic support specifically designed for mobile police populations was developed and tested. The reduction in interface pressure at the base of the seat back and the promotion of lumbar flexion angles that mimic non-occupational driving postures support the TS as an ergonomic intervention for both male and female mobile police officers. The reduction in interface pressure in the location of duty has the potential to reduce discomfort during longer exposure times. However, the TS increased posterior pelvic rotations compared to a standard seat. Based on the low discomfort reporting in both seating conditions, the reduction in pressure at the location of the duty belt and modifications in lumbar postures the TS intervention had favourable outcomes despite the increased posterior pelvic inclinations. Therefore, the results of the study indicate the thoracic support is ready for field testing in officers and future design iterations would benefit from testing longer exposure times to the seating intervention.

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