

Lumbar postures, seat interface pressures and discomfort responses to a novel thoracic support for police officers during prolonged simulated driving exposures

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ABSTRACT

A high prevalence of low back pain has been reported among professional drivers, including mobile police officers. The purpose of this investigation was to develop and evaluate a novel thoracic support designed for mobile police officers. Fourteen participants (7 male, 7 female) attended two 120-min driving simulations using a Crown Victoria Interceptor seat and the same seat equipped with a surface mounted thoracic support. Time-varying spine postures, seat pressures and ratings of discomfort were measured. Averaged discomfort values were low (less than 10 mm of a possible 100 mm) for both seating conditions. The postures in the thoracic support condition were more similar to non-occupational driving without occupational equipment than the Crown Victoria seating condition. The reduction in pressure area at the low back with the thoracic support has the potential to reduce discomfort reporting in officers compared to a standard vehicle package.

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1. Introduction

The in-vehicle space has become a mobile work environment for many professions. A link has been demonstrated in the literature between low back pain reporting and prolonged occupational driving exposures (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). Mobile police officers are considered prolonged occupational drivers based on annual mileage, which can exceed 40,000 km among some groups of officers (Gyi and Porter, 1998). Workers who drive in excess of 20 h a week are reportedly six times more likely to be absent from work with back pain than those who drive less than 10 h per week (Porter and Gyi, 2002). The reduction in lumbar lordosis that occurs during sitting

(De Carvalho et al., 2010; Keegan, 1953; Dunk and Callaghan, 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). During sitting in an automotive seat, previous research has demonstrated that lumbar lordosis decreases by an average of 43° compared to standing (De Carvalho et al., 2010).

In addition to prolonged occupational driving exposures, many modern mobile occupations require workers to complete office-based tasks within the vehicle's occupant compartment space. Approximately 50 percent of a police officer's shift is spent seated in a vehicle (Brown et al., 1998; McKinnon et al., 2011) and up to 33 percent of this in-vehicle time is spent performing data entry or retrieval activities on a dash board mounted laptop or mobile data terminal (MDT) (McKinnon et al., 2011). The introduction of MDTs in cruisers increases access to information (Agrawal et al., 2003), which in turn increases officer productivity (Hampton and Langham, 2005). However, use of these mobile devices also increases the potential for discomfort reporting. During lab simulated driving, the introduction of a typing task on an MDT increased discomfort reporting and increased posterior pelvic inclinations compared to driving alone (Gruevski et al., 2013). In a survey of municipal officers from a Canadian police force, the mean

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discomfort associated with in-vehicle computer use was 64 mm with 100 mm representing extreme discomfort (Donnelly et al., 2009).

There is evidence to suggest that in-vehicle lumbar supports are effective at increasing lordotic postures (De Carvalho and Callaghan, 2011a; Reed and Schneider, 1996; Andersson et al., 1974), reducing muscle activity (Kingma and van Dieën, 2009; Andersson et al., 1974) and reducing discomfort reporting among drivers (Chen et al., 2005). In a study conducted by Porter and Gyi (2002), drivers with seats that featured an adjustable lumbar support had fewer days absent from work with low back pain than drivers without a low back support. However, the mandatory equipment worn by officers (duty belt and Kevlar vest) makes a traditional lumbar support an infeasible ergonomic intervention for this population. In a recent investigation, the lumbar support was the seat feature that caused the greatest discomfort among surveyed officers with a mean rating of 50.9 mm out of a possible 100 mm (Donnelly et al., 2009). The duty belt and protective vest worn by officers create a unique interface between the seat and occupant that further increases the potential for discomfort reporting. The duty belt, side arm, radio and body armour were identified as causing the highest perceived discomfort of all equipment worn by officers throughout an 8-h shift (Donnelly et al., 2009). Interface pressure has been previously hypothesized as the objective measure with the strongest link to discomfort reporting during seated exposures (De Looze et al., 2003). It is possible that an intervention that reduces the seat back pressure in the location of the duty belt may also mitigate discomfort reporting in this region.

An Active Lumbar Support (ALS) seat was developed to accommodate the mandatory equipment worn by officers and successfully reduced discomfort reporting in both field and laboratory simulated driving environments (Donnelly et al., 2009). The ALS seat is a modified Crown Victoria seat with foam structural modifications to the thoracic region, a shortened seat pan and a mechanical component that translates in both superior/inferior and anterior/posterior directions (Donnelly et al., 2009). However, previous work has not examined if a thoracic support can induce changes to mitigate lumbar discomfort, improve lumbar lordosis or reduce interface pressures of the duty belt worn by police officers.

Assessing a novel thoracic intervention to provide support to the lumbar region and reduce discomfort while accommodating the body armour and duty belt was the focus of this investigation. The purpose of this study was to evaluate changes in lumbar spine posture and discomfort induced by a novel thoracic support during prolonged lab simulated driving. It was hypothesized that the thoracic support condition will lead to changes in posture and seat back contact to reduce low back discomfort, reduce seat pressure in the location of the duty belt and increase lumbar lordosis compared to a Crown Victoria seat alone.

2. Methods

2.1. Thoracic support development

A prototype thoracic support (TS) was developed to mimic the stiffness and shape of the ALS seat when the thoracic support was applied to a Crown Victoria seat. Differences in the seat back thickness and contours between the Crown Victoria and the ALS seats were used to design the dimensions and shape of the TS. Point cloud meshes of the surface contours of each seat were collected using a four marker digitizing probe (Northern Digital Inc., Waterloo, ON). Given that the ALS and Crown Victoria seats have identical metal frames, manually digitized points on the surface of both the Crown Victoria and ALS seats were expressed relative to a

common local coordinate system with its origin in the head rest of each seat. A one dimensional linear interpolation was applied to the point clouds collected from each seat to create 100 equally spaced points along the vertical dimension of the backrest in a custom MATLAB program (v.7.11.0, R2010b, Natick, MA, USA) so the points along the surface of each seat could later be aligned. A linear interpolation was selected due to the fine resolution (~1 mm) and the linear relationship between data points (Coburn and Crisco, 2005) with interpolated vertical slices of points on the surface of each seat calculated every 5 mm. The aligned surfaces were superimposed and the distance between interpolated points in the depth dimension were plotted to determine the difference between the Crown Victoria and ALS seats. The support mechanism in the ALS seat was scanned in three different positions within the range of the mechanism's translational adjustability including; highest, lowest and intermediate positions. The mechanism was tested in all three positions in both its fully extended and fully retracted states for a total of six surface scans of the ALS seat back. Surface contour differences between thoracic support locations were determined and a composite series of vertical cross-sections of the ALS seat were compared with the Crown Victoria seat. The scan of the ALS seat in the maximally extended and highest vertical position was used to design the support. The depth difference between this scan and the Crown Victoria seat was approximately 15 mm (Fig. 1). The edges of the thoracic support were tapered according to the scans to accommodate trunk rotation during MDT usage.

The stiffness of the ALS seat in its fully extended state was measured to select thoracic support foam to mimic its properties. The deflection properties of the ALS seat in the maximally extended setting were tested using an hand force dynamometer (Hoggan Health Industries, West Jordan, UT, USA), which was outfitted with 2 infrared markers (Northern Digital Inc, Waterloo, ON) to measure the excursion of the foam during the manual application of 100 N compared to the application of 0 N. The deflection properties of three 2.5 cm thick closed-cell foam samples were tested overlying the surface of the Crown Victoria seat and compared to the characteristics of the ALS seat. The Evazote EV50 foam (Zotefoams, Croydon, Surrey, England) deflected 0.54 mm more than the ALS and was used to build the prototype thoracic support. As 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 final prototype (Fig. 2). The uncompressed maximum thickness of the support was 2.5 cm, with outer dimensions of 30 cm long and 20 cm wide. The prototype was covered with a light textile fabric (Signature Textiles, Ref No. 87821, Saint-Laurent Québec).

2.2. Evaluation of thoracic support

2.2.1. Participants

Fourteen participants (7 male and 7 female) were recruited from a university student population (Table 1). 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. The study was approved by the University of Waterloo Office of Research Ethics. Participants were paired with similar absolute heights between genders (Table 1). Previous work examining prolonged driving exposures has demonstrated that when heights are matched between genders, postural differences in sitting disappear (Reed et al., 2000). A two-tailed t-test confirmed that the standing heights of female and male participants were not statistically different ($p = 0.2718$). Absolute participant heights represented a range of the male and female population (ANSUR, 1998). Ranges fell between 164–182 cm and 161–178 cm for males and females respectively.

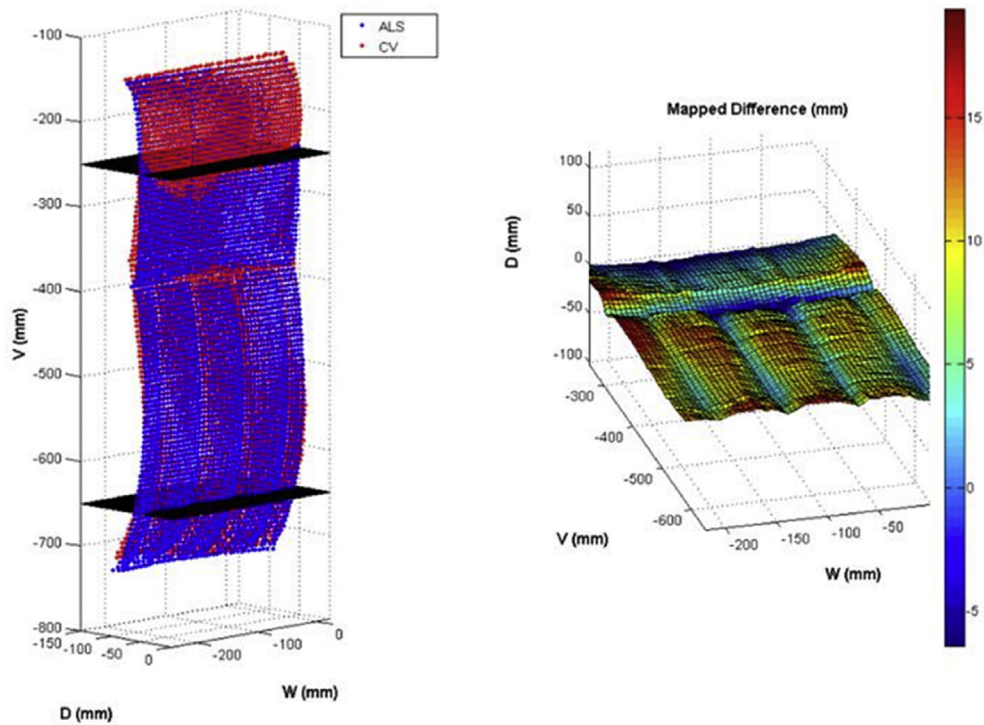


Fig. 1. Mapped differences between the maximally extended ALS position compared to the Crown Victoria (CV) seat. Mapped differences in the thoracic region are approximately 15 mm.

2.2.2. Protocol

The driving simulator was programmed using STISIM Drive (Systems Technology Inc., Hawthorne, CA, USA) to simulate high-way driving. The simulation images were projected onto a 2.65×1.5 m screen that was 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 (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) of the same dimensions and mass as regular equipment for the duration of the simulation. The location of items along the length of the belt was standardized across all conditions and represented the functional basic usage pattern for active officers.

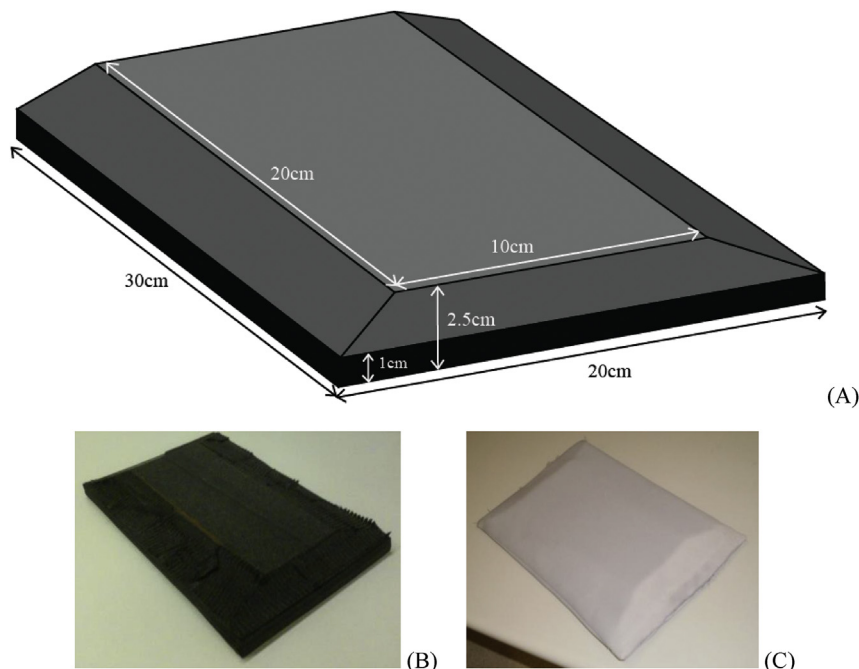


Fig. 2. Schematic representation of support (A), cut foam thoracic support (B) and covered support (C).

Table 1
Absolute heights of male and female participants.

Absolute heights (cm)		Absolute height difference (cm)	Age (years)		Mass (kg)	
Male	Female		Male	Female	Male	Female
164	161	3	19	22	89	57
168	163	5	21	30	60	68
168	168	0	23	21	67	75
169	171	2	20	19	77	77
169	171	2	21	19	86	61
175	174	1	25	30	75	61
182	178	4	20	22	73	77
171 (5.5)	169 (5.5)	$p = 0.2718$	21 (2.1)	23 (4.8)	75 (10)	68 (8.5)

Participants attended two 120-min driving simulation test sessions separated by a minimum of 24 h. Test sessions took place at the same time of day for each participant with the order of seating conditions (control and intervention) were randomized using a balanced minimization approach (Conlon and Anderson, 1990). The control session involved a standard Crown Victoria seat and the intervention condition consisted of the Crown Victoria seat in conjunction with the thoracic support applied to the surface of the seat. The thoracic support was secured to the seat with Velcro™ straps underneath the seat back pressure mat (which had an uncompressed thickness of 0.23 cm) to obscure any visual cues to the participants. The support was adjusted for each participant and the inferior edge was aligned with the bottom of the Kevlar vest. The driver's seat position was adjustable in the anterior/posterior direction within the constraints of an actual Ford Crown Victoria police vehicle with a 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 (Fig. 3). 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.

Each 2-h session was collected in 8 blocks of 15 min intervals and segmented into a total of 38 min of typing and 82 min of driving (Fig. 4). This ratio represents 33 percent of the 2-h collection in order to replicate the proportion of MDT usage that takes place during a mobile officer's shift (McKinnon et al., 2011). 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-min period and occurred at the beginning and end of the session

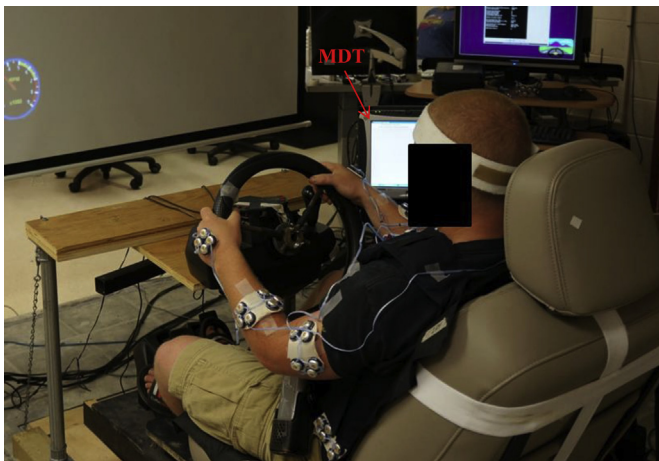


Fig. 3. Lab simulator setup during simulated driving.

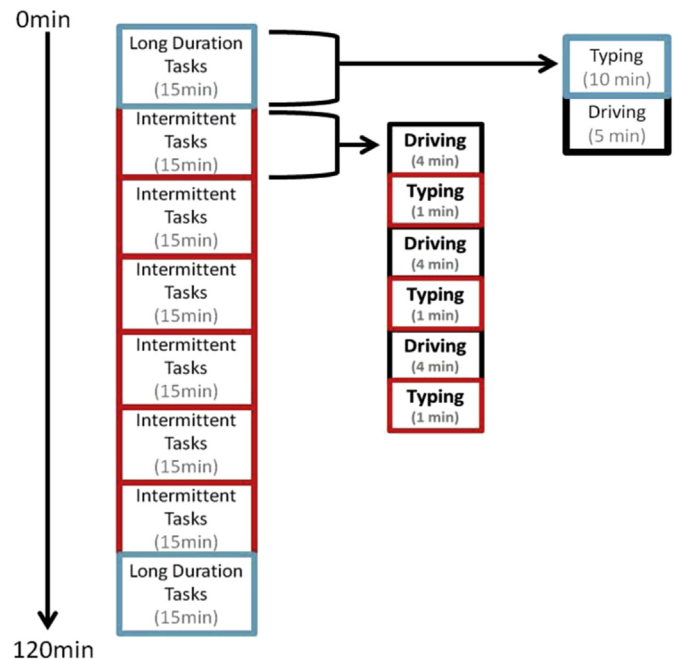


Fig. 4. Session protocol for all seating conditions including both long duration and intermittent driving and typing tasks.

(blocks 1 and 8). To replicate data retrieval and dispatch calls, intermittent typing tasks consisting of 1 min of typing responses to short answer questions triggered after every 4 min of driving.

2.2.3. Data collection and analysis

2.2.3.1. Discomfort. A custom made graphical user interface was generated using MATLAB (v.7.11.0, R2010b, Natick, MA, USA) to display a 100 mm visual analog scale to record ratings of perceived discomfort (RPD). RPDs were collected for 13 body locations including, the neck, left and right shoulders, left and right upper middle and low back, left and right buttocks and left and right thighs. Surveys were completed following each 15-min block with the first RPD recorded at baseline prior to the driving simulation for a total of 9 RPDs per session. The RPD was anchored on a scale from 0 mm, representing “no discomfort” to 100 mm representing “extreme discomfort.” The baseline discomfort was removed from all subsequent discomfort scores to isolate the response associated with the driving and MDT usage tasks.

2.2.3.2. Seat pressure. Two pressure-sensing mats (X3, XSensor Inc., Calgary, Alberta, Canada) were positioned on the seat pan and seat back to quantify pressure at the person–seat interface.

Pressure measurements were collected continuously for the full 120-min simulation in eight 15 min blocks and sampled at 8 Hz. 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 18×36 sensors) and the bottom of the seat back (bottom 18×36 sensors) were treated as separate dependent variables. The variables of interest were: (i) total pressure; calculated by adding the pressure readings from each active sensor in mmHg and (ii) the pressure area; calculated as a count of the number of active cells in each mat and then converted to cm^2 .

2.2.3.3. Lumbar and pelvic angles. Participants were instrumented with two tri-axial accelerometers (ADXL320, Analog Devices, Norwood, MA, USA) for the duration of the simulation to characterize lumbar spine posture and pelvic inclinations. The accelerometers were affixed to the skin over the spinous process of the first lumbar vertebrae and the first sacral vertebrae with double-sided tape and further secured with Hypafix tape (Smith & Nephew, Mississauga, ON, Canada) over each unit. To scale the accelerometer data to provide measures of inclination, participants completed five 5-s static 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. The accelerometer data were collected in eight continuous 15-min blocks at 1024 Hz for the full 120-min simulation. A 4th order Butterworth filter with a 1 Hz cutoff frequency (De Carvalho and Callaghan, 2011b) 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).

2.2.4. Statistics

The objective measures (pressure, accelerometry) were segmented into 4 distinct tasks; long duration typing, long duration driving (blocks 1 and 8), intermittent driving, and intermittent typing (blocks 2–7). Twenty seconds at the beginning and end of long duration typing and driving tasks and short duration driving were removed; and 10 s from the beginning and end of the intermittent typing tasks were removed. This removed variability in response time among participants to the auditory cue to begin each task. Processed sub-tasks (long duration driving, long duration typing, short duration driving and short duration typing) were then averaged within each time block. Two four-way mixed general linear models with repeated measures of time, seat and task and a between factor of gender were

completed on each type of tasks (SAS software, Version 8e for Windows, Cary, NC, USA). Tukey's *post hoc* test was used to examine significant time effects and interactions. Statistical significance was set at $\alpha = 0.05$.

Average changes in discomfort were analyzed over time (the duration of the simulation). A three-way mixed general linear model with repeated measures on seat and time was applied to discomfort scores. Planned pairwise comparisons were completed to examine significant time effects. Statistical significance was set at $\alpha = 0.05$. Prior to statistical testing, Mauchly's sphericity test was applied to both objective measures and discomfort scores 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.

3. Results

3.1. Discomfort

Average discomfort scores were low in the 13 body locations with all values remaining below 10 mm. Discomfort increased over the simulation duration regardless of backrest condition in six body locations ($p \leq 0.0421$) (Table 2). A significant ($p = 0.0016$) time by seat interaction existed where the thoracic support elicited lower neck discomfort scores early in the simulation, and increased discomfort (average increase of 2 mm) compared to the standard Crown Victoria seat over the final 30 min of the simulation. There was a significant ($p = 0.0473$) increase in average discomfort of 1.6 mm in the right thigh for the thoracic support seating condition. There was no effect of gender on average discomfort.

3.2. Seat interface pressure

3.2.1. Seat pan

There was no effect of gender, time or seating condition on the seat pan pressure area during either long duration or intermittent tasks. Seat pan total pressure increased significantly as a function of time during long duration tasks (blocks 1 and 8) with an average increase of 4579 mmHg from the first 15 min of the simulation to after 120 min of exposure ($p = 0.0304$). There was no main effect of time on the seat pan total pressure during intermittent tasks (blocks 2 to 7). There was a significant task by seat by gender interaction in the seat pan total pressure ($p = 0.0459$). The long duration typing (Fig. 5A) and driving tasks (Fig. 5B) are plotted separately in Fig. 5, but average total pressure changes were affected similarly for each task. The total pressure on the seat pan decreased with the thoracic support in males by an average of

Table 2
Average discomfort (\pm SD) over time across seating condition and gender, *p* values less than 0.05 are significant, with (*) indicating significant differences from time block 1.

Body location	Baseline removed discomfort (in mm) (±SD)								P-value
	Time (min)								
	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

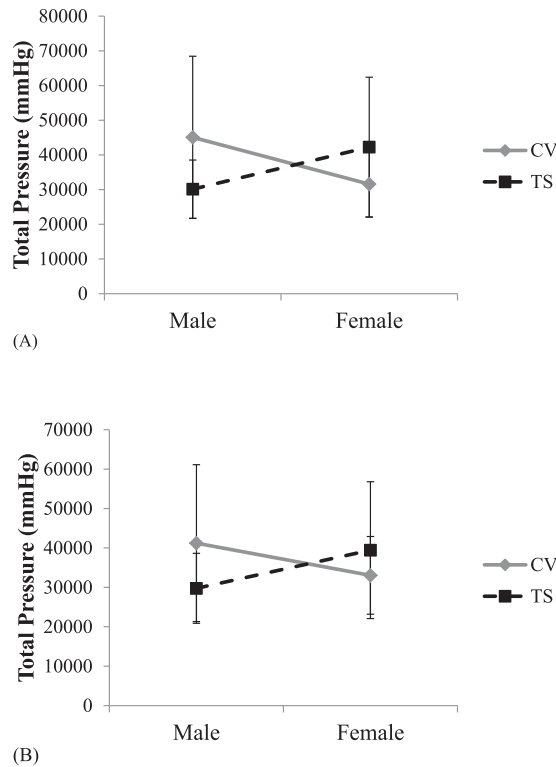


Fig. 5. Seat pan total pressure (\pm SD) by gender and seating condition during long duration typing (A) and driving tasks (B).

14947 mm Hg in driving and 11459 mm Hg in typing, but conversely increased in females by an average of 10677 mm Hg during driving and 6396 mm Hg during typing compared to the Crown Victoria seat.

3.2.2. Seat back

The seat back pressure area increased on the upper half of the seat back, but decreased on the bottom half of the seat back. During long duration tasks, there was a significant seat by time by task interaction on the pressure area of the upper half of the seat back ($p = 0.0299$). Specifically, the pressure area was higher with the thoracic support during typing compared to the Crown Victoria seating condition, but pressure values were similar during the driving task. During typing, the pressure area in the thoracic support seating condition had a more rapid increase over time than the Crown Victoria seating condition (Fig. 6A). The opposite pattern occurred in the driving condition; where the Crown Victoria seating condition had a more rapid increase (Fig. 6B). In long duration tasks, there was a significant seat by task interaction on the pressure area of the lower half of the seat back ($p = 0.0074$). The thoracic support had a greater influence on reducing the pressure area during the driving task where the pressure area was reduced an average of 209 cm² compared to the typing task where there was an average reduction in pressure area of 162 cm² with the thoracic support (Fig. 6C). A similar effect was present during the intermittent tasks; where there was a significant seat by task interaction ($p = 0.0205$) in the lower half of the seat back. While the pressure area was reduced by the thoracic support during both driving and typing tasks, the reduction was greater during driving tasks. There was no effect of gender, time or seating condition on the seat back total pressure during either the long duration or intermittent tasks.

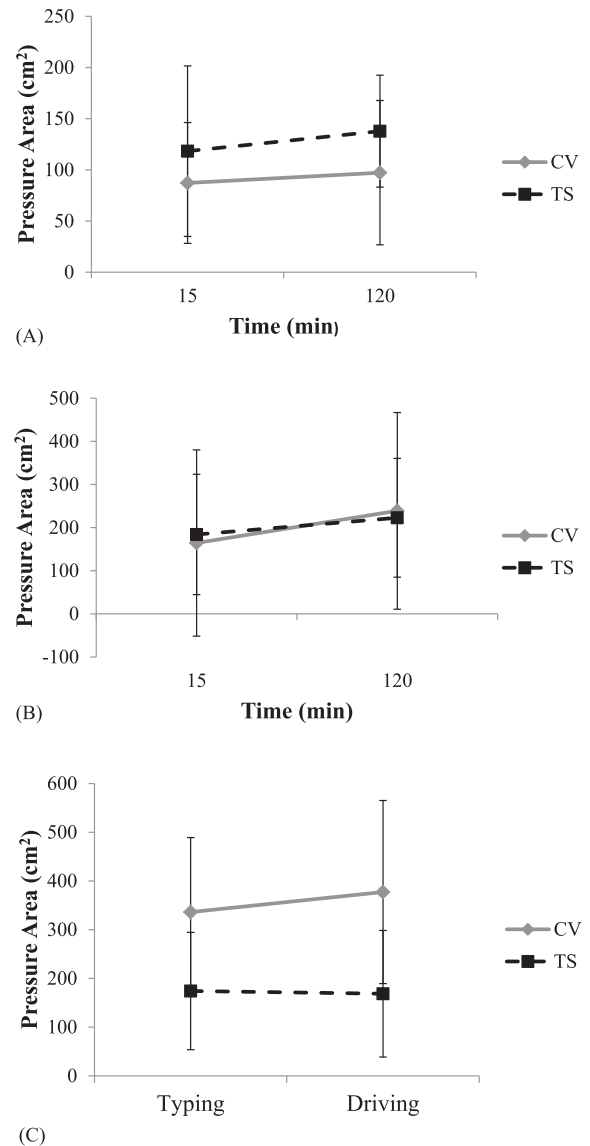


Fig. 6. Seat back pressure area. Upper seat back pressure area (\pm SD) during long duration typing (A) and driving (B) tasks for blocks 1 and 8. Pressure area (\pm SD) on the lower half of the seat back during long duration driving and typing tasks (C).

3.3. Lumbar and pelvic angles

The thoracic support significantly affected lumbar and pelvic postures compared to the Crown Victoria seat. There was a main effect of seating condition during both the long duration ($p = 0.0069$) (Fig. 7A) and intermittent tasks ($p = 0.0118$) on normalized lumbar angles. Specifically, the lumbar angles in the Crown Victoria seating condition are closer to standing values, whereas the postures in the thoracic support seating condition represent increased lumbar flexion. There was no main effect of gender or time on lumbar angles during the long duration tasks. 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% from time block 2 to time block 7. There was also a significant task by gender interaction ($p = 0.0055$) where male participants had greater lumbar flexion during the typing task than female participants, but flexion angles were similar during the driving tasks. There was a significant seat by gender interaction in pelvic inclinations during both the long duration ($p = 0.0393$)

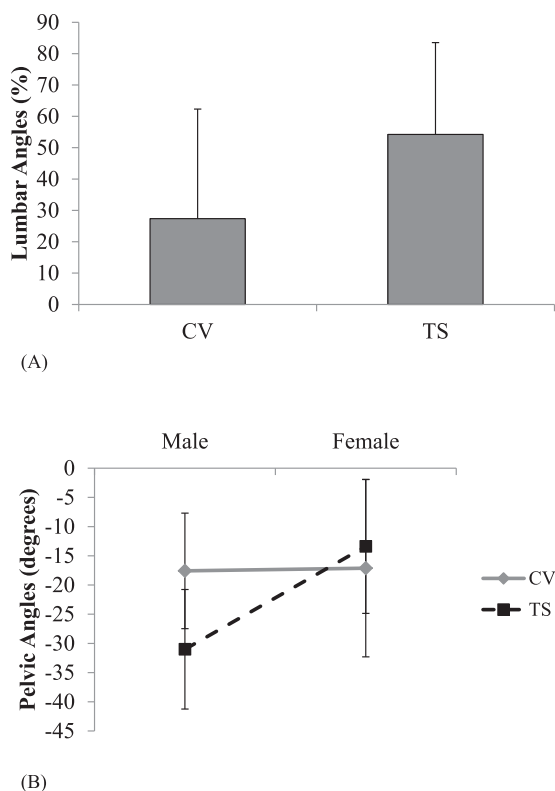


Fig. 7. Normalized lumbar flexion angle (\pm SD) by seating condition during long duration tasks (A) Pelvic inclinations (\pm SD) during long duration tasks by seating condition and gender. Pelvic inclinations are presented as angles that deviate from the vertical with negative values representing posterior pelvic inclinations and positive values representing anterior pelvic inclinations (B).

(Fig. 7B) and intermittent tasks ($p = 0.0455$) where women had a greater reduction in posterior pelvic rotation with the thoracic support while males had greater posterior pelvic rotation with the support. 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 over time in driving.

4. Discussion

The postural, pressure and discomfort responses to a novel thoracic support were determined during a 120-min exposure to simulated occupational driving. There were differences in seated postures, interface pressures and discomfort responses between the Crown Victoria and thoracic seating conditions. The responses were shown to interact with gender, time and the in-vehicle task performed. The effects are considered in the context of a highly constrained laboratory experiment.

Both seating conditions maintained lumbar postures within a healthy range of motion with the thoracic support condition eliciting postures closer to non-occupational driving. Previous work has documented an increased lumbar lordosis with the use of a lumbar support during in-vehicle seating (De Carvalho and Callaghan, 2012; Reed and Schneider, 1996; Andersson et al., 1974); however, direct comparison with our study is difficult because these investigations did not involve the use of on-person occupational equipment. Postures in the thoracic support condition were more similar to non-occupational driving (without equipment) (De Carvalho and Callaghan, 2011b) than the Crown Victoria seating condition. In long duration tasks, the Crown

Victoria seating condition elicited 27.7% more extended postures and the thoracic support elicited 0.8% more extended postures compared to the second hour of non-occupational driving (De Carvalho and Callaghan, 2011b). The present study found averaged (standard deviation) 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 and Callaghan (2011b). The Crown Victoria seating condition in the present study elicited more lordotic postures than the thoracic support condition. The averaged postures during the Crown Victoria seating condition were 27.3 (34.9) % during long duration blocks and 29.7 (36.0) % during the intermittent blocks. More lordotic postures do not necessarily reduce discomfort reporting (De Carvalho and Callaghan, 2011a). In-vehicle lumbar supports have been shown to increase lumbar lordosis compared to no support without altering pelvic posture (De Carvalho and Callaghan, 2012). This increase in lordosis with a fixed pelvis has been shown to increase discomfort reporting (De Carvalho and Callaghan, 2011a) and this has been 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 being closer to standing values while sitting (De Carvalho and Callaghan, 2011a). The thoracic support may therefore have the potential to improve range of motion at the lumbosacral junction during sitting with on-person occupational equipment. A recent investigation conducted by Holmes et al. (2013) compared lumbar postures between a standard duty belt configuration and a modified configuration that removed items on the belt from the low back area. Normalized lumbar postures had greater flexion with the reduced belt compared to the standard belt with 34.5 (29.9) % and 27.5 (27.8) %, respectively. This demonstrates that even when duty belt items are removed from the lumbar area, participants elected to sit in more flexed postures. In the present investigation, the thoracic support was shown to bear increased pressure on the upper back, participants also elected to sit with greater flexed postures. Given that all participants were recruited from a University student population, it was assumed that the postures of a student population would replicate those of police officers during patrol. As law enforcement hiring practices do not enforce height and weight restrictions in Canada, it is reasonable to assume that students are anatomically representative of a police population. The study was a simulation of occupational driving in a highly constrained, laboratory environment to logistically permit instrumentation. Further, the duration of exposure to the driving scenario and the thoracic support intervention may have been too low to induce more realistic levels of discomfort experienced by patrol officers. It is possible that long exposure duration in a field scenario would provide further insights.

The reduction in interface pressure on the seat back with the thoracic support has the potential to reduce discomfort reporting in officers compared to a standard vehicle package. The seat back pressure area increased on the upper half of the seat back, but decreased on the bottom half of the seat back with the thoracic support compared to a Crown Victoria seat. The lower half of the seat is in direct contact with the equipment found on the officer's duty belt. The duty belt, side arm, radio and body armour were the articles of equipment rated as causing the highest perceived discomfort by surveyed officers (Donnelly et al., 2009). Previous work has demonstrated that focal pressure distributions have a strong association with sitting discomfort (De Looze et al., 2003). The results of the present investigation demonstrate less contact area as measured by pressure area in the lower part of the seat back, which is the location of high discomfort reported in police

officers (Donnelly et al., 2009). The seat pan total pressure decreased with the thoracic support in males, but increased in females. This difference could be explained by backrest usage. Previous work indicates that females generally sit closer to the seat edge than males in both office chairs (Dunk and Callaghan, 2005) and during simulated occupational driving (Gruevski et al., 2013).

Discomfort responses were low in both seating conditions and comparable to previous work. Discomfort increased in the right thigh and the neck with the thoracic support compared to the Crown Victoria seating condition. Despite the increases in discomfort found during the thoracic condition over time, the control seat exhibited similar time dependent increases and both seats were comparable to previous work investigating prolonged occupational driving (Holmes et al., 2013). Average discomfort scores were found to be low with scores in all body locations below 10 mm. Lumbar supports have been effective in reducing reported discomfort over time compared to a standard seat (Donnelly et al., 2009). This may be due to the reduction in focal pressure at the low back area caused by the duty belt. The protective vest worn by officers likely diffuses focal pressure from the thoracic support. Previous work examining low back pain and driving suggests that high cumulative exposure to driving leads to increased low back pain (Porter and Gyi, 2002). During the intermittent blocks, participants were cued every 4 min with an auditory tone and instructed to type for 1-min. It is possible that continuous sitting (without MDT usage) may induce discomfort to development more rapidly. There is also evidence to suggest that distraction can reduce perceived pain (Eccleston and Crombez, 1999).

The time varying responses to the simulation were similar to previous work with the exception of lumbar postures. Normalized lumbar flexion angles decreased by an average of 6.8% from block 2 to block 7 during the intermittent typing tasks across both seating conditions. There was no statistically significant difference in lumbar flexion angles during the long duration tasks. These findings differed from previous work that reported 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, which have been hypothesized as a factor leading to increased trunk flexion over time during prolonged simulated driving exposures (Callaghan et al., 2010). Both seat pan total pressure and subjective discomfort increased over time. This is consistent with previous work for both seat pan pressure (Callaghan et al., 2010) and discomfort measures (De Carvalho and Callaghan, 2011b; Callaghan et al., 2010; Gruevski et al., 2013).

5. Conclusions

A prototype thoracic support specifically designed for mobile police populations was developed and tested. The support was found to reduce seat back contact area in the location of high discomfort reporting and increase contact area in the upper back. This redistribution of contact area has the potential to reduce discomfort reporting among officers. The postures in the thoracic support condition were more similar to non-occupational driving than the Crown Victoria seating condition while discomfort responses were low in both seating conditions. As the study was a lab-based simulation, future design iterations of the thoracic support would benefit from in field testing among officers, with longer exposure times to the seating intervention.

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