International Journal of Occupational Safety and Ergonomics (*JOSE*) 2009, Vol. 15, No. 3, 295–307

The Effect of an Active Lumbar System on the Seating Comfort of Officers in Police Fleet Vehicles

Cyril J. Donnelly

Faculty of Life and Physical Science, University of Western Australia, Perth, Australia

Jack P. Callaghan
Jennifer L. Durkin

Faculty of Applied Health Sciences, University of Waterloo, Waterloo, ON, Canada

The purposes of this study were to determine which seat features/occupational demands contributed to police officer discomfort and whether an automobile seat fitted with an active lumbar system (ALS) could reduce driving discomfort. Fifty-eight officers were given questionnaires to assess driving discomfort. High discomfort levels were associated with computer use, duty belt, sidearm/radio, body armour and lumbar support interface. Discomfort was highest in the lumbar, sacrum, upper pelvis and mid-back regions. Twelve officers spent one shift each in a police vehicle seat and an ALS seat. Discomfort was assessed every 2 h during 8-h shifts. Reduced discomfort was reported with the ALS seat. Three lumbar support features, the duty belt, and the lumbar and right upper pelvis regions, showed reduced discomfort. Overall seat discomfort decreased by 47% after 8 h of exposure to the ALS. Modifying the automobile seat helps to reduce officer discomfort during prolonged vehicle usage.

driving low back discomfort police officers active lumbar system massage automobile seat

1. INTRODUCTION

In both public and occupational sectors, increased driving distances and commute times have been shown to increase the risk of developing musculoskeletal disorders [1, 2, 3, 4, 5]. In an occupational setting, people exposed to daily prolonged driving situations (>4 h per day) have almost double the risk of missing work due to lower back pain compared to occupational groups not exposed to prolonged driving situations [1, 5]. Approximately one quarter of police officers are considered prolonged drivers (>25 000 km per annum) [2]. Eighteen percent of this population reports *always* or *often* experiencing lower back pain during driving and misses ~3 times as many working days per year relative to police officers not exposed to prolonged driving [2].

Presently, most car seats are designed to optimally accommodate the 50th percentile adult male [6]. Police populations typically include many individuals whose body mass and stature anthropometrics are in the upper quartile of the general male and female populations [7, 8].

Funding was gratefully provided by the AUTO21 Network of Centers of Excellence and Leggett and Platt Automotive Group, a division of Leggett and Platt Incorporated. Dr. Jack P. Callaghan is supported by a Canada Research Chair in Spine Biomechanics and Injury Prevention.

Correspondence and requests for offprints should be sent to Jennifer L. Durkin, Department of Kinesiology, Faculty of Applied Health Sciences, University of Waterloo, Waterloo, ON, Canada N2L 3G1. E-mail: <durkinjl@healthy.uwaterloo.ca>.

Additionally, restrictions of vehicle space and seat adjustability due to occupational equipment requirements create an environment that limits the ability to appropriately accommodate officers within the automobile. As a result, police officers may be at greater risk of developing discomfort during vehicle usage compared to other individuals.

The ability for a seat to accommodate a driver has been found to be related to the onset and magnitude of driver discomfort [9]. Further, the use of a lumbar support system has been shown to aid in the maintenance of a person's natural lordotic lumbar curvature during sitting [10, 11] which has been associated with reducing lower back discomfort [12, 13]. The use of lumbar massage systems in automobile seats have also been shown to reduce lower back discomfort [14, 15]. It is thought that these interventions reduce discomfort by increasing or maintaining local tissue nutrition [14, 16].

Due to the unique requirements of police officers wearing both body armour and a duty belt at all times, the location of lumbar support may not provide the same relief for this population of vehicle users. The purpose of this study was to determine which seat features, occupational equipment and tasks were related to officer discomfort during prolonged vehicle usage. A second purpose of the study was to examine the efficacy of an automobile seat fitted with an active lumbar support system (ALS) in reducing driving discomfort.

2. METHODS

This study was comprised of two phases. Phase 1 of the study was designed to (a) determine which seat features and occupational equipment created the largest amounts of discomfort in a police population and (b) determine which body regions were most affected. Phase 2 of the study was intended to (a) determine the time-varying changes in driving discomfort reported by a police population over a standard 8-h shift and (b) examine the efficacy of an ALS in reducing driving discomfort during a standard 8-h shift.

Both phase 1 and phase 2 of this investigation received ethics approval from the University of Waterloo Research Ethics Committee prior to contact with any participating officers. Full co-operation was granted by the Windsor Police Service (Windsor, ON, Canada).

2.1. Phase 1

Fifty-eight officers (Table 1) were given 2 one-time questionnaires at the beginning of a shift. None of the officers had experienced lower back pain that would cause them to miss a day of work or not to perform tasks of daily living in the 12 months preceding the survey.

TABLE 1. Mean (*SD*) Age, Mass and Height of Participants in Phase 1

Gender	*n*	Age (years)	Stature (m)	Body Mass (kg)
Males	49	35.7 (7.5)	1.84 (0.07)	99.2 (15.0)
Females	9	35.6 (10.5)	1.70 (0.04)	68.6 (7.4)

The first questionnaire consisted of 30 questions designed to determine ratings of perceived discomfort related to specific automobile seat features, occupational equipment and tasks (Figure 1). This questionnaire was adapted from a previously validated automobile seat discomfort questionnaire [17]. The second questionnaire included ratings of perceived discomfort scales for 20 specific body regions to help determine the body regions that most experience discomfort during a typical shift (Figure 2). This questionnaire was adapted from a previously validated questionnaire by Mergl, Klendauer, Mangen, et al. [18]. All discomfort ratings were recorded on a 100-mm visual analog scale (VAS), with 0 mm representing *no discomfort* and 100 mm representing *extreme discomfort*.

Officers were given the questionnaires at the beginning of their shift. The 8-h shift start times varied and included morning (6 a.m.), afternoon (2 p.m.) and evening shifts (11 p.m.) from two separate police precincts within the same city. Officers were instructed to rate their discomfort levels related to the given question during a typical shift.

To answer each question place a vertical dash [|] ***through*** *the corresponding line*

	No Objections	Extreme Objections
1. In terms of how the upholstery (trim) feels, I have…	|	|
2. Discomfort due to trim	|	|
3. Discomfort produced by friction with upholstery	|	|

	No Discomfort	Extreme Discomfort
4. Discomfort due to the width of the seat cushion	|	|
5. Discomfort due to seat cushion length	|	|
6. Discomfort due to seat cushion firmness	|	|

	No Discomfort	Extreme Discomfort
7. Discomfort caused by seat cushion bolsters (sides)	|	|
8. Discomfort caused by the centre of the seat cushion	|	|
9. Discomfort caused by contour of the seat cushion	|	|

	No Discomfort	Extreme Discomfort
10. Discomfort produced by the height of the back rest	|	|
11. Discomfort due to back rest width	|	|
12. Discomfort due to firmness of back rest	|	|

	No Discomfort	Extreme Discomfort
13. Discomfort produced by the back rest bolsters (sides)	|	|
14. Discomfort due to backrest contour	|	|
15. Discomfort created by lumbar stiffness	|	|

Scale Continued on NEXT PAGE

To answer each question place a vertical dash [|] ***through*** *the corresponding line*

	No Discomfort	Extreme Discomfort
16. Discomfort produced by low back support	|	|
17. Support created by the low back support has…	|	|
18. The vertical location of the low back support causes…	|	|
19. Pressure created from the low back support has…	|	|

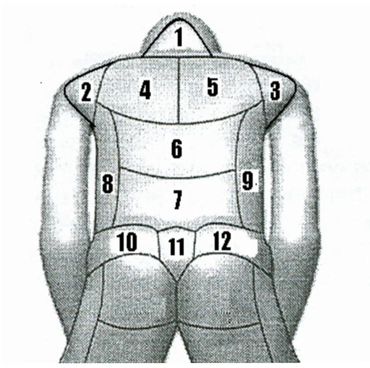
	No Discomfort	Extreme Discomfort
20. Discomfort due to computer use	|	|
21. Discomfort due to radio use	|	|
22. Discomfort caused by getting into car seat	|	|
23. Discomfort caused by getting out of car seat	|	|

	No Discomfort	Extreme Discomfort
24. Discomfort caused by soft body armour	|	|
25. Discomfort caused by side arm/radio	|	|
26. Discomfort caused by duty belt	|	|
27. Discomfort caused by equipment on back of duty belt	|	|
28. Discomfort caused by asp	|	|
29. Discomfort caused by seatbelt	|	|

	No Discomfort	Extreme Discomfort
30. This seat has an overall discomfort level of….	|	|

Figure 1. Seat components and occupational demands questionnaire. *Notes.* Adapted from Smith, Andrews and Wawrow [17]. Visual analog scales were 100 mm long.

*To answer each question place a vertical dash [|] **through** the corresponding line*

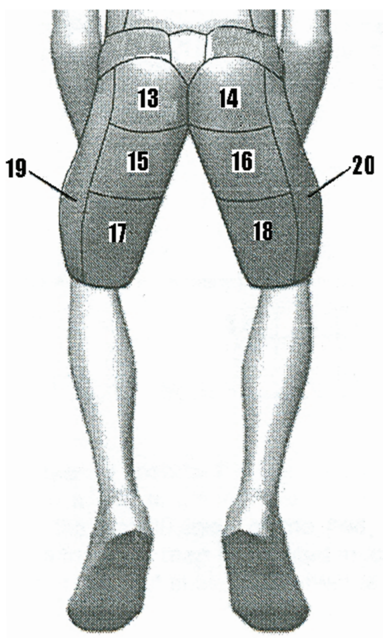


The number displayed in the regions in the diagram above correspond with the numbers in the survey to the right of the diagram.

	No Discomfort	**Extreme Discomfort**
1. Neck	|————————————	|
2. (L) Shoulder	|————————————	|
3. (R) Shoulder	|————————————	|
4. (L) Upper Back	|————————————	|
5. (R) Upper Back	|————————————	|
6. Middle Back	|————————————	|
7. Lower Back	|————————————	|
8. (L) Side of Body	|————————————	|
9. (R) Side of Body	|————————————	|
10. (L) Upper Pelvis	|————————————	|
11. Sacrum/tail bone	|————————————	|
12. (R) Upper Pelvis	|————————————	|

Scale Continued on NEXT PAGE

*To answer each question place a vertical dash [|] **through** the corresponding line*



	No Discomfort	**Extreme Discomfort**
13. (L) Buttocks	|————————————	|
14. (R) Buttocks	|————————————	|
15. (L) Upper Thigh	|————————————	|
16. (R) Upper Thigh	|————————————	|
17. (L) Lower Thigh	|————————————	|
18. (R) Lower Thigh	|————————————	|
19. (L) Side of Leg	|————————————	|
20. (R) Side of Leg	|————————————	|

Approximate total time spent sitting in the cruiser during the last 2 hours: ___________ (hrs:mins)
Approximate time spent sitting in the cruiser since you last entered the vehicle: __________ (hrs:mins).
Approximate number of times you left the cruiser in the last 2 hours: ___________

Figure 2. Body region discomfort questionnaire. *Notes.* Adapted from SAE paper 2005-01-2690 © SAE International [18]. Visual analog scales were 100 mm long.

2.2. Phase 2

Ten male and 10 female police officers were recruited from the same police force. Each of these officers had also participated in phase 1 and were randomly selected from this group. None of these officers had experienced lower back pain that would cause them to miss a day of work or not to perform tasks of daily living in the 12 months preceding the study. Data was collected during two separate shifts (6 a.m. or 2 p.m. start time). During one shift, officers used a vehicle equipped with a standard automobile seat. The other shift involved using a vehicle equipped with seat that contained an ALS (Schukra of North America, Canada) as well as modifications to the foam structure to accommodate the equipment on the duty belt (Figure 3). Only driving officers were included in the study. The ALS was a prototype that, when manually initiated by the driver, produced cyclic anteroposterior excursions of the lumbar support with a cycle time of 20 s. The system ran for 10 min after which the driver was required to re-initiate the mechanism. The ALS also contained features enabling support adjustment for the mid-thoracic to pelvic regions through both vertical and horizontal positioning of the support mechanism. Assessment of these two seats was performed in random order. Further, data collection from a given officer occurred at the same time of day for each seat (e.g., both assessments done during a 6 a.m. or 2 p.m. shift).

Officers were given a package at the beginning of their shift consisting of five sets of questionnaires. The questionnaires were identical to the questionnaires used in phase 1 of the investigation (Figures 1–2). Questionnaires were completed at 2-h intervals over an 8-h shift starting at time 0. For the ALS trials, officers were trained to use the lumbar support features of the ALS seat prior to the start of the shift. Officers were instructed to run the massage component of the ALS for a minimum of 10 min at the start of each 2-h interval. Due to

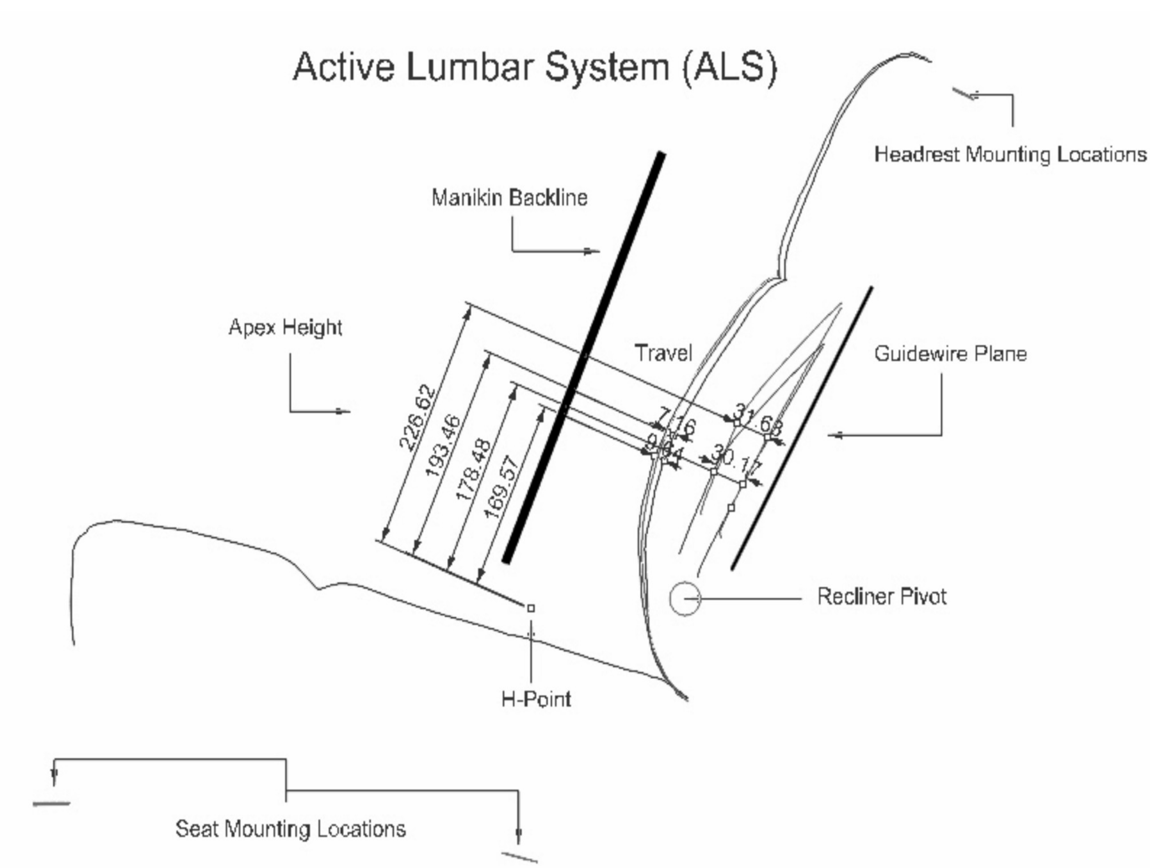


Figure 3. Schematic of the active lumbar support system (ALS). *Notes.* Reprinted with permission from Leggett and Platt Automotive Group.

occupational factors requiring officers to be outside of their vehicle for prolonged periods of time during their shift as well as a limited availability of female officers, complete data from 8 male and 4 female officers were obtained (Table 2) and are included in the reported results.

TABLE 2. Mean (*SD*) Age, Mass and Height of Participants in Phase 2

Gender	*n*	Age (years)	Stature (m)	Body Mass (kg)
Males	8	30.5 (5.0)	1.85 (0.10)	98.6 (16.7)
Females	4	33.8 (7.0)	1.69 (0.04)	65.0 (1.1)

2.3. Statistical Analysis

Data from phase 1 were assessed by calculating mean ± standard deviation discomfort ratings for each of the 30 questions and 20 body regions surveyed. A rating of perceived discomfort score greater than 30 mm was considered clinically significant. A two-way repeated measures general linear model (GLM) with seat (2 levels) and time (5 levels) as factors was run on data from phase 2. Each question was examined independently and Tukey's HSD post hoc analysis was run when statistically significant ($\alpha = .05$) differences were found.

3. RESULTS

3.1. Phase 1

The seat feature creating the greatest level of officer discomfort was the low back support (50.9 ± 32.3 mm). Specifically, the lumbar support stiffness (42.5 ± 32.9 mm), the vertical location of the lumbar support (37.1 ± 32.2 mm) and the pressure created by the lumbar support (37.0 ± 32.5 mm) created the greatest amount of discomfort amongst the seat features examined. The mean overall discomfort rating for the seat was 49.5 ± 27.3 mm out of 100 mm. The equipment and tasks that created the greatest level of discomfort were computer use (64.0 ± 30.9 mm), followed by the duty belt (63.2 ± 29.0 mm), sidearm/radio (52.7 ± 26.5 mm), soft body armour (48.6 ± 29.5 mm), vehicle egress (48.4 ± 31.5 mm) and vehicle ingress (45.0 ± 33.3 mm) (Figure 4).

The body region discomfort questionnaire revealed that the low back experienced the greatest discomfort (57.2 ± 30.2 mm) followed by the sacrum/tail bone (41.1 ± 34.1 mm), right (36.9 ± 35.2 mm) and left (34.0 ± 34.1 mm) upper pelvis and middle back (31.2 ± 26.1 mm)

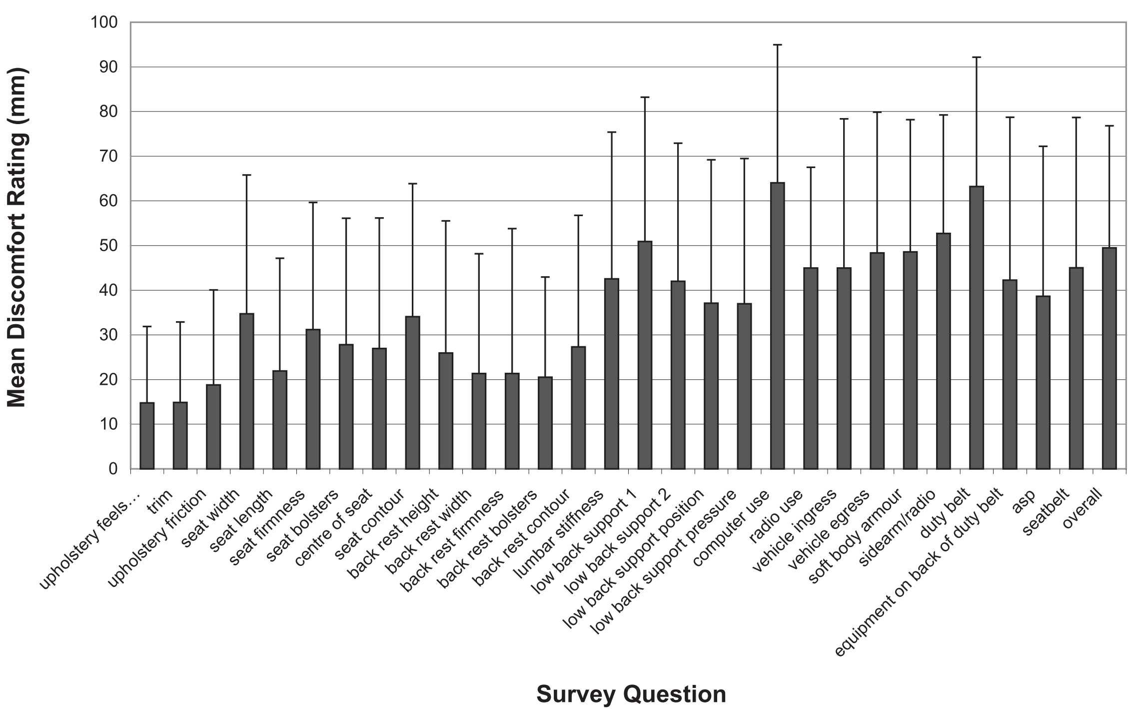


Figure 4. Mean (*SD*) discomfort ratings of seat components and occupational demands questionnaire.
Notes. Values are in millimeters on a 100-mm scale.

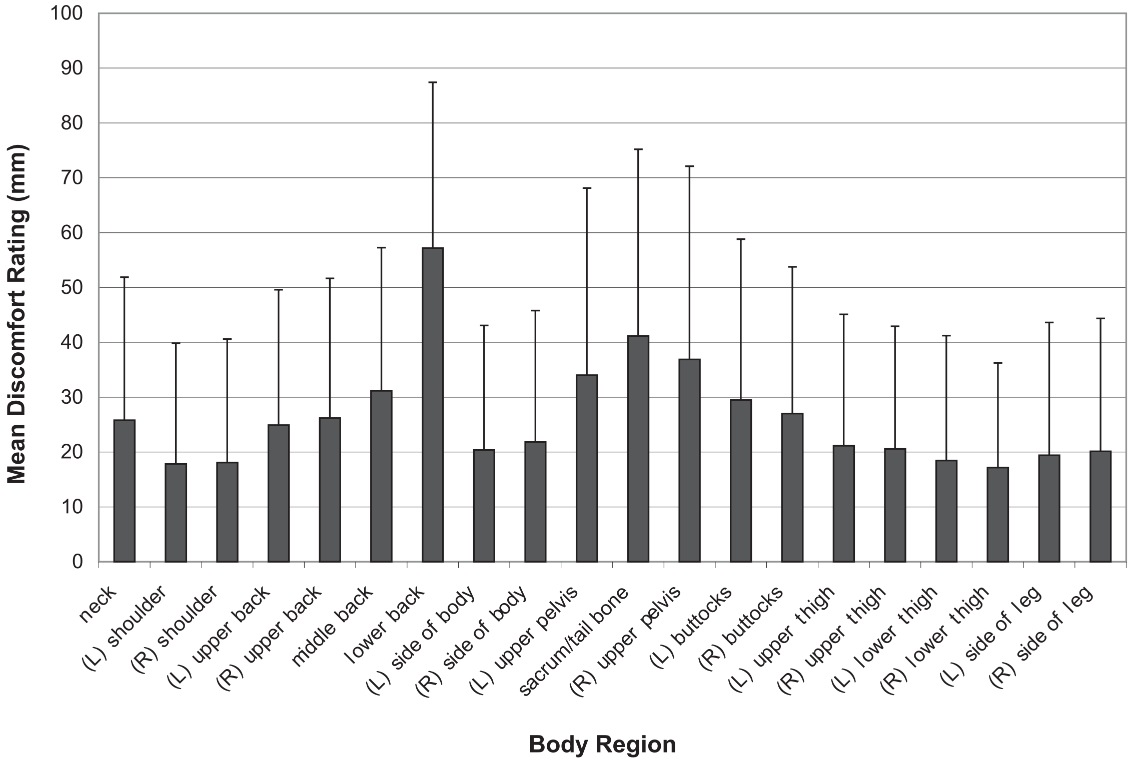


Figure 5. Mean (*SD*) discomfort ratings by body region. *Notes.* Values are in millimetres on a 100-mm scale.

(Figure 5). All other body regions, seat features and occupational equipment caused discomfort levels >10 mm on a 100-mm scale.

3.2. Phase 2

The time-varying responses of the ALS and control seats showed that the ALS had significantly lower discomfort levels than the control seat where the low back support was concerned (p = .048). Specifically, the position of the low back support (p = .033) and the pressure caused by the low back support (p = .031) showed significantly lower discomfort ratings with ALS use. Discomfort due to the duty belt was significantly reduced (p = .045) as was mean overall discomfort (p = .034) (Table 3, Figure 6a). After 8 h, overall discomfort was on average 21.2 mm lower with the ALS than with the control seat which is considered a large treatment

TABLE 3. Mean (*SD*) Reduction in Ratings of Perceived Discomfort After 8 h of Exposure to the ALS Seat Compared to the Control Seat

Question Category	Question/Region Description	Reduction in Discomfort (%)	*F*	*p*
Seat component	discomfort produced by low back support (Q16)	34.8 (14.9)	4.93	.048
	support created by low back support (Q17)	39.6 (16.3)	5.32	.042
	vertical location of the low back support (Q18)	31.6 (13.0)	5.94	.033
	pressure created by low back support (Q19)	36.3 (14.3)	6.15	.031
	seat overall discomfort level (Q30)	47.0 (16.4)	5.42	.034
Occupational demand	discomfort caused by duty belt (Q26)	69.1 (19.0)	5.13	.045
Body region	lower back (R7)	34.8 (16.1)	5.93	.033
	right upper pelvis (R12)	26.2 (9.8)	5.99	.032

Notes. Only statistically significant differences are reported. ALS—active lumbar support system; Q—question, R—region.

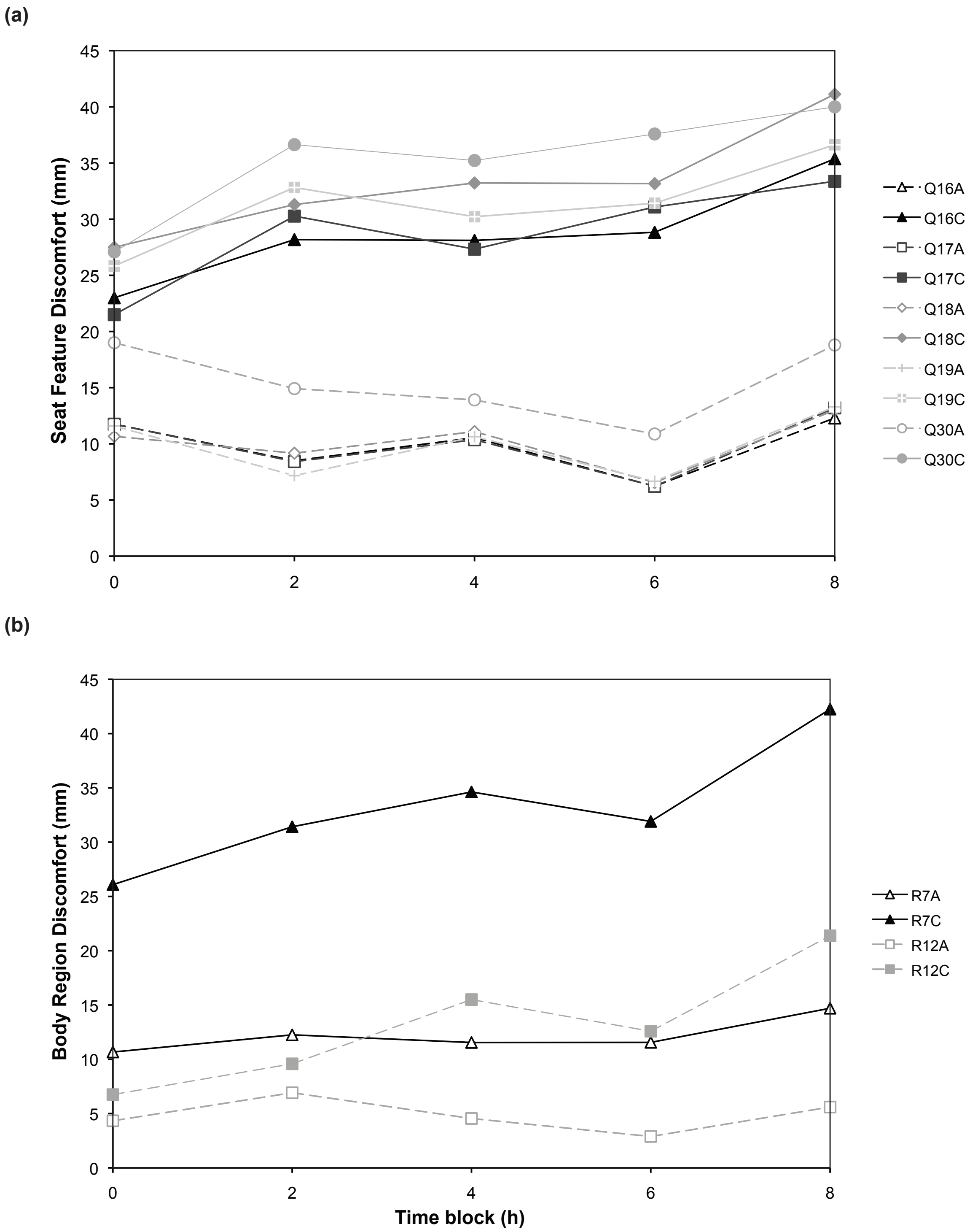


Figure 6. Mean time-varying responses of (a) seat components, occupational demands and (b) body region discomfort when using an active lumbar support system (ALS) versus a control seat. *Notes.* Only statistically significant differences between seats are reported. Descriptions of each question number are provided in Table 3. A and C refer to the ALS or control seat, respectively.

effect [19]. The ALS also resulted in significantly lower low back (p = .33) and right upper pelvis (p = .032) region discomfort (Table 3, Figure 6b).

Significant time effects were found for the seat pan bolsters (p = .032), back rest width (.001), radio use (.021), vehicle egress (.028), mid-back (.009), low back (.014), right upper pelvis (.012) and sacrum/tailbone (.049) regions (Figure 7). In all cases, discomfort significantly increased with time. No significant seat × time interactions were found.

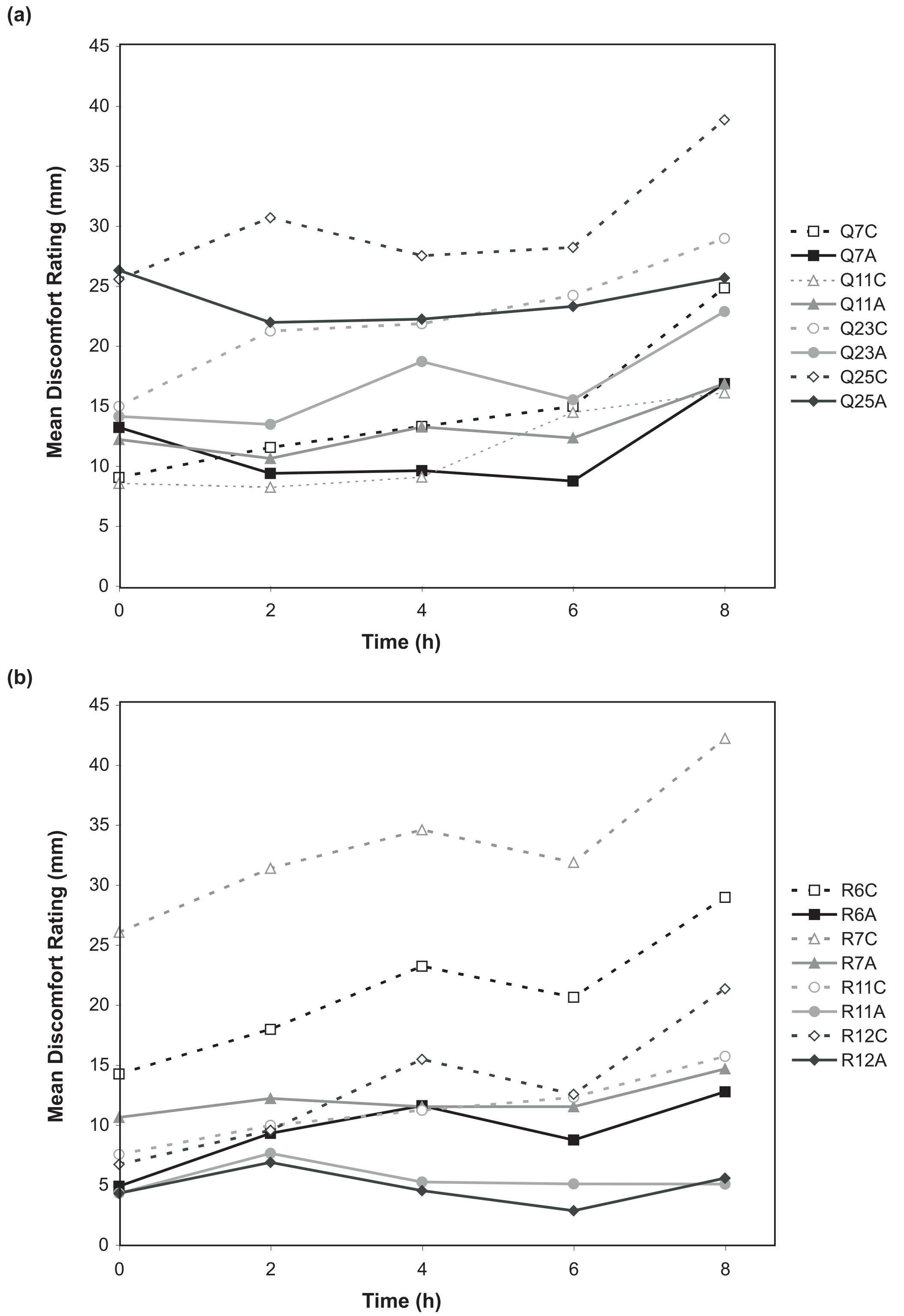


Figure 7. Mean time-varying responses of (a) seat components, occupational demands and (b) body region discomfort when using an active lumbar support system (ALS) versus a control seat. *Notes.* Only statistically significant differences with respect to time are reported. Q7—seat pan bolsters, Q11—backrest width, Q23—vehicle egress, Q25—sidearm/radio use, R6—mid-back, R7—low back, R11—sacrum/tailbone, R12—right upper pelvis. A and C refer to the ALS or control seat, respectively.

4. DISCUSSION

The results from phase 1 demonstrated that officers experienced elevated levels of discomfort in the low back, sacrum, right and left upper pelvis, and middle back regions. The discomfort ratings for these specific regions were >30 mm and the mean discomfort ratings for all regions were >10 mm. This lends support to previous findings that police populations routinely exposed to prolonged driving experience elevated ratings of low back discomfort [2] compared to officers not exposed to these conditions.

There are several factors that may have contributed to officer discomfort within the vehicle. The spatial constraints of standard police cruisers force officers to work in a severely cramped environment. Space is limited within these vehicles due to the presence of occupational equipment including a laptop computer that is attached to the vehicle console. Further, a cage meant to protect officers from individuals detained in the rear of the vehicle limits seat adjustability including the horizontal tracking and seat back recline mechanisms. The inability to fully adjust seat positions during a shift will cause an increase in discomfort over time [3, 20] and may lead to a related musculoskeletal injury in the future.

Police officers must wear specific equipment on their person including soft body armour and a duty belt with an asp baton, firearm, radio and restraint systems on their waist. This equipment may alter driving posture and impose peak pressures at the driver–seat interface not typically experienced by the average driver. An increase in peak pressures in the posterior thoracic, lumbar and pelvic regions likely contributed to the elevated ratings of discomfort reported by the officers when in the control seat [18, 21].

Officers reported elevated levels of discomfort when using the in-cruiser computer. Use of the computer requires that officers axially rotate their torsos from their midline and maintain this posture for prolonged periods of time. Associations between rotated trunk postures and the development of low back pain have been reported [22, 23]; therefore, the requirement to maintain fixed rotated postures when using the computer system is a likely contributor to the elevated discomfort ratings reported by officers in the low and middle back regions.

The use of an ALS seat reduced discomfort in police officers during prolonged vehicle usage. This was evident by the statistically significant decreases in ratings of perceived discomfort related to the lumbar support, overall seat characteristics, duty belt, and lumbar and right upper pelvic regions. The ALS seat likely helped reduce discomfort for several reasons. First, the seat foam contour was altered compared to the control seat in that foam was removed from the lumbar region to accommodate equipment on the duty belt. Further, the lumbar support was adjustable in the vertical and anterior/posterior directions. The altered foam contour and increased adjustability enabled a driver-controlled modulation of peak pressures in the lumbar region while seated in the ALS seat. Peak pressure magnitudes have been associated with elevated ratings of discomfort [18, 21]; therefore, the ability of an officer to alter the peak pressures imposed by their occupational equipment likely helped to reduce low back and pelvic discomfort.

Individuals typically adopt flexed lumbar postures while driving [24, 25, 26]. Such postures have been shown to increase a person’s probability of developing degenerative disk disorders [27] and lumbar disc herniation [28]. Prolonged lumbar flexion is also thought to elevate low back discomfort through increased loading of the passive tissues of the lumbar spine [29], tissues which are highly innervated with nociceptors [30, 31, 32]. The ability to maintain lumbar lordosis while minimizing peak pressures on the lumbar spine are important for decreasing low back discomfort [12, 13]. Control of the anterior/posterior and vertical positions of the lumbar support likely allowed officers to maintain a more lordotic lumbar posture while minimizing the pressures produced by the lumbar support. The long-term effects of this reduction may be a decrease in chronic musculoskeletal pain and injury.

The active feature of the ALS seat involved a system that, when manually initiated by the driver, produced cyclic anteroposterior excursions of the lumbar support. The system ran for 10 min after which the driver was required to re-initiate the mechanism. The contribution of this active component to the reduction in perceived discomfort ratings is difficult to separate from the other seat features. It is likely that the active component contributed to the decreased discomfort ratings as previous research has indicated that massage units can increase or maintain blood flow to the low back region during driving [14]. Maintenance of circulation to tissues prevents the onset of local ischemia [21] thereby resulting in decreased local tissue discomfort [33].

Officers were instructed to initiate the ALS at the start of their shift and a minimum of 10 min every 2 h. They were also permitted to activate the unit more often if they wished, however ALS usage statistics during the driving trials were not available. It is, therefore, unknown how much the officers used the active component of the system.

A limitation that may have impacted the discomfort ratings reported in this investigation was the inability to blind the participants to the conditions that they were exposed to. Officers were aware of which seat they were using and as such, there was no way to prevent a user bias towards the modified seat. It is assumed, however, that any bias towards the ALS seat would disappear through the duration of the shift if the seat did not truly improve comfort with its use.

Statistically significant reductions in discomfort were found for several seat components and occupational demands. Kelly found that a 10-mm difference in VAS scores represented a small treatment effect, whereas a 20-mm difference represents a large treatment effect [19]. Each of the significant seat component and occupational demand ratings except for the duty belt (12.7 mm reduction) amounted to a mean difference >20 mm after 8 h. Further, the sidearm/radio displayed a reduction of 13.2 mm after 8 h with the ALS seat even though no statistically significant difference was found. Discomfort ratings in the low back and right upper pelvis also displayed significant differences between the two seats. After 8 h of exposure to the ALS seat, the mean differences in discomfort were 27.6 and 15.8 mm, respectively. However, according to Kelly, several other body regions displayed small treatment effects with the use of the ALS including the neck (11.4 mm), mid-back (16.2 mm), left side of the body (14.5 mm), left upper pelvis (15.7 mm), sacrum/tailbone (10.7 mm) and right lower thigh (12.0 mm). The results of this study, therefore, demonstrate that the use of the ALS seat markedly reduced officer discomfort related to a variety of seating components, occupational demands and in a number of body regions.

This study demonstrates that there is a large amount of discomfort associated with prolonged sitting in police vehicles. Accommodation of occupational equipment, the ability to make seat adjustments in the mid-back, lumbar and pelvic regions throughout a shift, and the presence of ALS together helped reduce discomfort during prolonged vehicle usage for police officers. The contributions of the individual seat modifications to reductions in discomfort are not yet known. Further investigations into how such modifications alter driving posture, seat contact pressure and pelvic and spine kinematics during driving is, therefore, needed. The findings support the use of a modified automobile seat that includes the ability to accommodate the equipment worn by officers during their shift. These modifications decreased ratings of discomfort during a typical shift spent within a police cruiser and, therefore, have the potential to reduce the likelihood of developing pain and/or musculoskeletal injury from this occupational task.

REFERENCES

1. Chen JC, Chang WR, Chang W, Christiani D. Occupational factors associated with low back pain in urban taxi drivers. Occup Med (Lond). 2005;55:535–40 (DOI: 10.1093/occmed/kqi125). Retrieved June 17, 2009, from: http://occmed.oxfordjournals.org/cgi/reprint/55/7/535
2. Gyi DE, Porter JM. Musculoskeletal problems and driving in police officers. Occup Med

(Lond). 1998;48:153–60. Retrieved June 17, 2009, from: http://occmed.oxfordjournals.org/cgi/reprint/48/3/153

3. Porter JM, Gyi DE. The prevalence of musculoskeletal troubles among car drivers. Occup Med (Lond). 2002;52:4–12. Retrieved June 17, 2009, from: http://occmed.oxfordjournals.org/cgi/reprint/52/1/4
4. Sakakibara T, Kasai Y, Uchida A. Effects of driving on low back pain. Occup Med (Lond). 2006;56:494–6 (DOI: 10.1093/occmed/kql045). Retrieved June 17, 2009, from: http://occmed.oxfordjournals.org/cgi/reprint/56/7/494
5. Walsh K, Varnes N, Osmond C, Styles R, Coggon D. Occupational causes of low-back pain. Scand J Work Environ Health. 1989;15:54–9.
6. Kolich M. Automobile seat comfort: occupant preferences vs. anthropometric accommodation. Appl Ergon. 2003;34:177–84.
7. Hsiao H, Long D, Snyder K. Anthropometric differences among occupational groups. Ergonomics. 2002;45:136–52.
8. Smolander J, Louhevaara V, Oja P. Policemen's physical fitness in relation to the frequency of leisure-time physical exercise. Int Arch Occup Environ Health. 1984;54:295–302.
9. Gyi DE, Porter JM. Interface pressure and the prediction of car seat discomfort. Appl Ergon. 1999;30:99–107.
10. Carcone SM, Keir PJ. Effects of backrest design on biomechanics and comfort during seated work. Appl Ergon. 2007;38:755–64.
11. Lengsfeld M, Frank A, van Deursen DL, Griss P. Lumbar spine curvature during office chair sitting. Med Eng Phys. 2000;22:665–9.
12. Chen JC, Dennerlein JT, Chang CC, Chang WR, Christiani DC. Seat inclination, use of lumbar support and low-back pain of taxi drivers, Scand J Work Environ Health. 2005;31:258–65.
13. Makhsous M, Lin F, Hendrix RW, Hepler M, Zhang LQ. Sitting with adjustable ischial and back supports: biomechanical changes. Spine. 2003;28:1113–21.
14. Durkin JL, Harvey A, Hughson RL, Callaghan JP. The effects of lumbar massage on muscle fatigue, muscle oxygenation, low back discomfort, and driver performance during prolonged driving. Ergonomics. 2006;49:28–44.
15. Kolich M, Taboun SM. Combining psychophysical measures of discomfort and electromyography for the evaluation of a new automotive seating concept. International Journal of Occupational Safety and Ergonomics (JOSE);2002;8:483–96.
16. Goats GC. Massage—the scientific basis of an ancient art: part 2. Physiological and therapeutic effects. Br J Sports Med. 1994;28:153–6.
17. Smith DR, Andrews DM, Wawrow PT. Development and evaluation of the automotive seating discomfort questionnaire (ASDQ). Int J Ind Erg. 2006;36:141–9.
18. Mergl C, Klendauer M, Mangen C, Bubb H. Predicting long term riding comfort in cars by contact forces between human and seat (Paper No. 2005-01-2690). Warrendale PA, USA: SAE International; 2005.
19. Kelly A-M. Does the clinically significant differences in visual analog scale pain scores vary with gender, age, or cause of pain? Acad Emerg Med. 1998;5:1086–90.
20. Frymoyer JW, Pope MH, Clements JH, Wilder DG, MacPherson B, Ashikaga T. Risk factors in low-back pain. An epidemiological survey. J Bone Joint Surg Am. 1983;65-A:213–8. Retrieved June 17, 2009, from: http://www.ejbjs.org/cgi/reprint/65/2/213
21. Swain I. The measurement of interface pressure. In: Bader DB, Bouten C, Colin D, Oomens C, editors. Pressure ulcer research. Berlin, Germany: Springer; 2005. p. 51–70.
22. Hoogendoorn WE, Bongers PM, de Vet HC, Douwes M, Koes BW, Miedema MC, et al. Flexion and rotation of the trunk and lifting at work are risk factors for low back pain: results of a prospective cohort study. Spine. 2000;25:3087–92.
23. West DJ, Gardner D. Occupational injuries of physiotherapists in North and Central Queensland. Aust J Physiother. 2001;47:179–86.

24. Beach TM, McDonald KA, Coke SK, Callaghan JP. Gender responses to automobile and office sitting—influence of hip, hamstring, and low-back flexibility on seated postures. The Ergonomics Open Journal. 2008;1:1–9. Retrieved June 17, 2009, from: http://www.bentham.org/open/toergj/
25. Donnelly CJ. The influence of body mass on posture, pressure distribution and discomfort during prolonged driving [Master of Science thesis]. Waterloo, ON, Canada: University of Waterloo; 2007.
26. Reed MK, Saito M, Kakishima Y, Lee NS, Schneider LW. An investigation of driver discomfort and related seat design factors in extended-duration driving (Paper No. 910117). Warrendale PA, USA: SAE International; 1991.
27. Videman T, Nurminen M, Troup JD. 1990 Volvo Award in clinical sciences. Lumbar spinal pathology in cadaveric material in relation to history of back pain, occupation, and physical loading. Spine. 1990;15:728–40.
28. Kelsey JL, Hardy RJ. Driving of motor vehicles as a risk factor for acute herniated lumbar intervertebral disc. Am J Epidemiol. 1975;102:63–73.
29. Callaghan JP, Dunk NM. Examination of the flexion relaxation phenomenon in erector spinae muscles during short duration slumped sitting. Clin Biomech. 2002;17:353–60.
30. Cavanaugh JM. Neural mechanisms of lumbar pain. Spine. 1995;20:1804–9.
31. Jackson HC, Winkelmann RK, Bickel WH. Nerve endings in the human lumbar spinal column and related structures. J Bone Joint Surg Am. 1966;48:1272–81.
32. Pedersen HE, Blunck CF, Gardner E. The anatomy of lumbosacral posterior rami and meningeal branches of spinal nerve (sinu-vertebral nerves); with an experimental study of their functions. J Bone Joint Surg Am. 1956;38-A:377–91.
33. Gregory DE. Prolonged standing as a precursor for the development of low back discomfort: an investigation of possible mechanisms [Master of Science thesis]. Waterloo, ON, Canada: University of Waterloo; 2005.