

# The Impact of Mobile Data Terminal Use on Posture and Low-Back Discomfort When Combined With Simulated Prolonged Driving in Police Cruisers

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*The introduction of mobile computing within a constrained vehicle environment has led to changes in the task demands of occupational groups such as professional drivers and law enforcement officers. The purpose of this study was to examine how mobile data terminal (MDT) use interacts with prolonged driving to induce postural changes or low-back discomfort. Eighteen participants (9 male, 9 female) completed two 120-min simulated driving sessions. Time-varying lumbar spine and pelvis postures, seat pan interface pressures and ratings of perceived discomfort were recorded at 15-min intervals. The introduction of a computer interface decreased pelvic posterior rotation by an average of 15° with respect to upright standing and increased peak average discomfort in the neck (5.9 mm), left shoulder (6.8 mm), midback (10.9 mm), low back (10.6 mm) and pelvis (11.5 mm) compared to driving alone. The incorporation of mobile computing warrants consideration in the design of vehicle work environments.*

occupational driving   low-back discomfort   mobile data terminals   police officers

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## 1. INTRODUCTION

Professional drivers including police officers spend substantial parts of their working shift in their vehicle, either driving or performing work related tasks, increasing the risk of injury. Police officers as a group are considered prolonged drivers with annual mileage greater than 40 000 km with 18% of exposed officers always or often experiencing low-back pain [1]. There is an increased prevalence of back pain associated with professional drivers including bus drivers [2, 3, 4, 5], taxi drivers [6] and mobile police officers [7]. The flexion of the lumbar spine required in seated postures has been hypothesized as a potential risk factor for low-back pain by several researchers [8, 9, 10, 11, 12].

In addition to the occupational driving demands of law enforcement, many police forces are now adopting in-vehicle computing systems or mobile data terminals (MDT). It has been reported that nearly 50% or 6 h of an urban region officer's shift is spent seated in a vehicle and on average 40% of in-vehicle time is associated with performing data entry or retrieval activities with the MDT [13]. While the MDT can increase productivity among officers [14, 15] and provides increased access to information and resources, the impact of in-vehicle computing and links to musculoskeletal pain need to be considered. Subjective questionnaire responses have shown that low-back support as a seat feature, computer use and the duty belt worn by officers were the greatest sources of discomfort during in-vehicle

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activities [16]. It has been shown that men and women respond to prolonged sitting exposures differently [17, 18]. The design of automobile seats and the physical demands of operating a vehicle constrain postural adjustments more than office-based seated work [9]. It has been documented that women sit close to the edge of the seat pan in office chairs [18]; while in automobile sitting, women sit further back in the seat pan and use the backrest to a greater degree [9].

While there have been several studies examining the perceived discomfort reported by police officers, the impact of seat design and MDT configuration, and the impact of the addition of computer use in conjunction with prolonged driving have not been previously examined. The purpose of this investigation was to examine how the introduction of a computer interface in conjunction with prolonged driving influences postural variables and subjective discomfort during prolonged simulated police vehicle work. A secondary objective was to examine gender specific responses to the driving and MDT use tasks.

## 2. METHODS

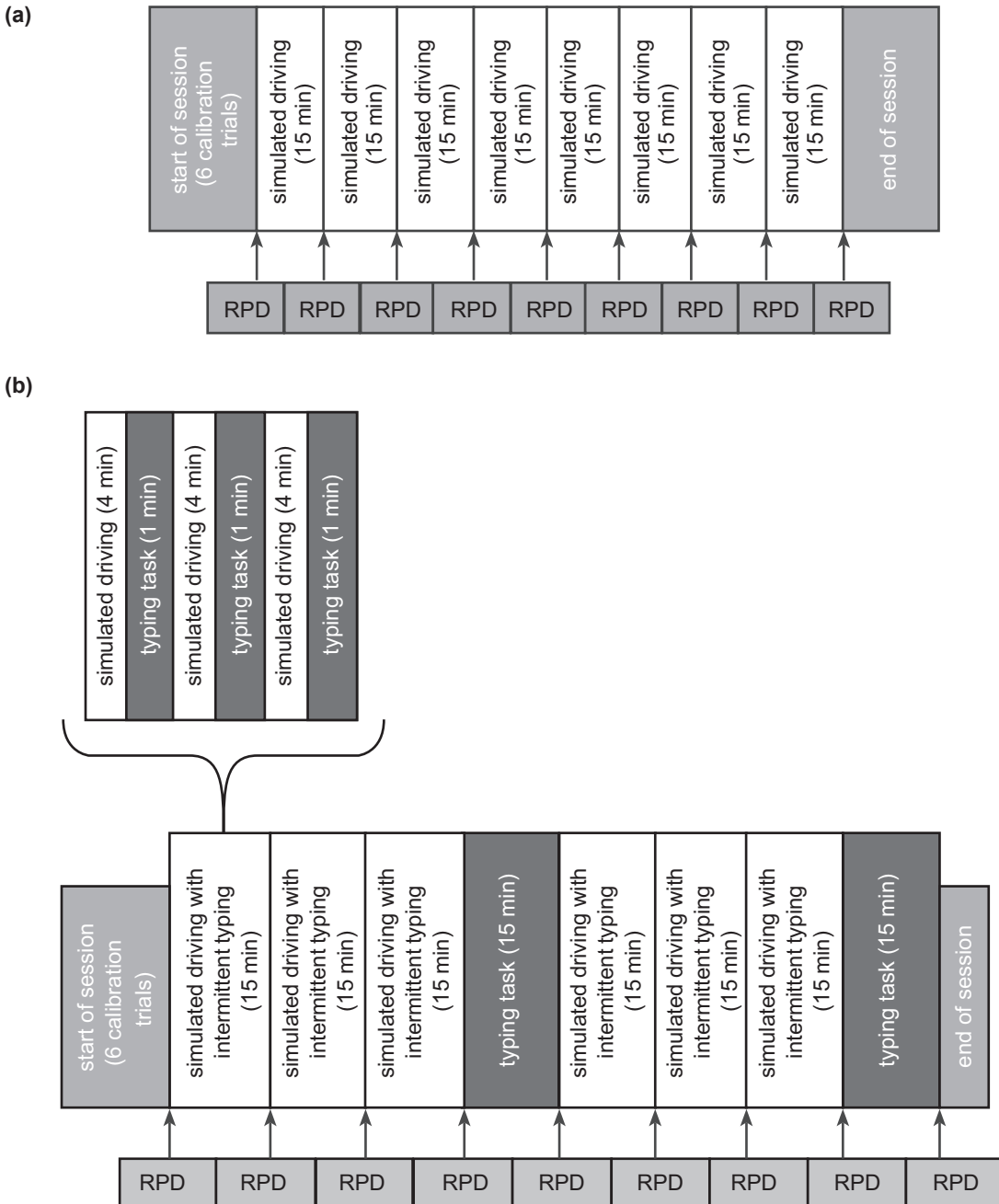
Eighteen participants, 9 female ( $23.1 \pm 2.4$  years,  $164.0 \pm 10.6$  cm,  $60.4 \pm 9.2$  kg) and 9 male ( $24.2 \pm 2.8$  years,  $185.7 \pm 6.9$  cm,  $91.4 \pm 11.7$  kg) were recruited from a university student population. Participants were free of any low-back or upper-extremity musculoskeletal disorders at the time of collection. Informed consent was obtained prior to testing. The study was reviewed by, and received ethics clearance through, the Office of Research Ethics, University of Waterloo, Canada.

Participants attended two 120-min driving simulation test sessions separated by at least 24 h. Two conditions were tested: prolonged driving with and without an intermittent typing task (Figure 1) with the order of task conditions randomized. The typing condition consisted of eight blocks of 15-min intervals segmented into a total of 48 min of typing and 72 min of driving. This ratio represented 40% of the 2-h collection to replicate the proportion of typing that takes place during a mobile officer's shift [13]. The intermit-

tent typing tasks consisted of 1 min of typing responses to short answer questions for every 4 min of driving to replicate data retrieval and dispatch calls. The long-answer questions consisted of typing long-answer questions for a full 15-min period to replicate report entry tasks performed by police officers. The lumbar spine and pelvic angles and seat interface pressures were analyzed over two of the 15-min blocks, 45–60 and 105–120 min, which were blocks of continuous typing. The responses during these time blocks were compared to the same time blocks during the prolonged driving trials to isolate how the participants responded to MDT use after driving and how this differed for the postures and seat-participant interface during driving alone.

The simulator setup was designed to mimic the internal dimensions and configuration of the Ford Crown Victoria Interceptor and device surrogates were used to replicate the on-person equipment of officers (Figure 2). The location of the car seat was self-selected within the range of seat fore/aft adjustability of the Ford Crown Victoria Interceptor. The location of the MDT was in a previously documented location used by a regional police force [19]. The driving simulation program, STISIM Drive (Systems Technology, USA), consisted of straight roads with minor bends to simulate highway driving. Participants were instructed to maintain speeds of 80–100 km/h, as confirmed visually by the participants. The simulation images were projected onto a  $1.9 \times 1.5$  m screen located 3 m in front of participants. All participants wore a personal police protective vest and a 4.75-kg duty belt with device surrogates of the same dimensions and mass as regular equipment (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) for the duration of the simulation.

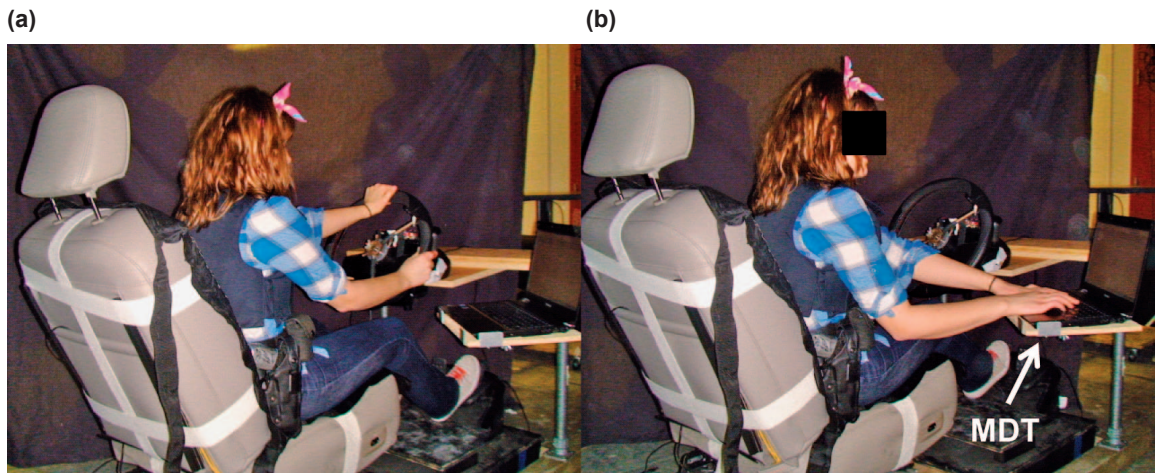
Two 15-g tri-axial accelerometers (S2-10-g-MF; NexGen Ergonomics, Canada) were used to collect time-varying lumbar angles during the simulation trials. The accelerometers were affixed to the skin over the first lumbar vertebrae and sacral vertebrae with double-sided tape. To scale



**Figure 1. Experimental design: (a) driving condition, (b) typing condition.** Notes. The order of conditions was randomized. Ratings of perceived discomfort (RPD) were recorded at baseline and after each 15-min interval, a total of 9 ratings.

the accelerometer data to provide measures of inclination, six calibration trials preceded the prolonged driving trials: quiet sitting, quiet standing, moving to full lumbar flexion while sitting, moving to full lumbar flexion while standing, held full lumbar flexion during sitting and held full lumbar flexion during standing. The upright standing posture was used as the neutral or zero

position and time-varying lumbar angles were normalized to the maximum lumbar flexion angle achieved in the calibration trials. A 16-bit analog-to-digital converter (Optotrak data acquisition unit; NDI, Canada) was used to transform the analog voltage outputs from the accelerometers into discrete signals. The accelerometer data was collected in eight 15-min blocks at 1024 Hz for



**Figure 2. Lab simulator setup: (a) simulated driving, (b) simulated driving with an intermittent typing task.** Notes. MDT = mobile data terminal.

the full 120-min simulation. A second-order dual pass Butterworth filter with a 1-Hz cut-off frequency was used and then converted to normalized range of motion using a custom Matlab program version 7.11.0.

A capacitive pressure mapping system with two mats (X3; XSensor, Canada) was used to quantify the pressure interfaces on the seat pan and seat back panel during the driving trials. Pressure measurements were collected for the full 120-min simulation in eight 15-min blocks and sampled at 5 Hz. Ratings of perceived discomfort (RPD) were recorded on a 100-mm visual analog scale for 12 body locations including the neck, left and right shoulder, upper back, midback, low back, pelvis, sacrum, left and right buttock, and left and right thigh at 15-min intervals throughout the collection. The first RPD was recorded at baseline prior to the driving simulation; a total of nine RPD scores were collected. The RPD was anchored on a scale from 0 (*no discomfort*) to 100 mm (*the most discomfort possible*). The baseline discomfort at each session was removed from all subsequent discomfort scores.

A three-way (gender  $\times$  task  $\times$  time) mixed general linear model with repeated measures on task and time was completed on peak average discomfort, seat pan centre of pressure, lumbar angles and pelvic angles. Tukey's post hoc tests were used to detect significant time effects and any interactions. Statistical significance was set at  $\alpha = .05$ .

### 3. RESULTS

Peak discomfort in each body location at any time point in the simulation was averaged across participants. The typing condition was found to significantly increase average peak discomfort in the neck (5.9 mm), left shoulder (6.8 mm), mid-back (10.9 mm), low back (10.6 mm) and pelvis (11.5 mm) compared to driving alone (Table 1). The low back was the area of greatest subjective discomfort during the typing task, increasing peak discomfort scores to an average of 30.2 mm. There were no significant gender differences in discomfort found in any of the 12 body locations.

The pelvis was significantly less posteriorly rotated ( $p = .001$ ) during the typing task compared to the driving task (Figure 3a). There was also a reduced posterior tilt in women compared to men across both tasks ( $p = .026$ ). There was no significant change in lumbar posture across gender, task or time. However, there was a significant ( $p = .022$ ) time-by-task interaction in lumbar angle (Figure 4). As the length of driving exposure increased, lumbar angles became less flexed. However, when MDT use was introduced, the lumbar angles became more flexed later in the prolonged exposure. There was a significant ( $p < .001$ ) time-by-task interaction in the anterior-posterior direction of seat pan centre of pressure (Figure 5a). As the length of exposure increased, participants sat more anteriorly on the seat pan during the typing condition. In the driving condition, there was no

TABLE 1. Peak Average Discomfort by Task Across Gender

Body Location	Driving (mm)	Typing (mm)	<i>p</i>
Neck	3.7 (7.8)*	9.6 (10.2)	.043
Left shoulder	2.7 (5.4)*	9.5 (9.3)	.017
Right shoulder	2.5 (5.6)	8.1 (9.6)	.053
Upper back	7.2 (11.0)	10.2 (10.6)	.421
Midback	8.6 (9.2)*	19.5 (13.4)	.002
Low back	19.6 (22.9)*	30.2 (17.8)	.046
Pelvis	9.9 (20.4)*	21.4 (24.4)	.004
Sacrum	10.8 (21.3)	20.3 (22.5)	.142
Left buttock	9.3 (12.9)	15.4 (21.5)	.120
Right buttock	8.9 (13.3)	17.7 (24.1)	.066
Left thigh	3.3 (4.5)	11.0 (20.6)	.089
Right thigh	10.2 (16.3)	12.2 (22.8)	.710

Notes. \**p* = .05.

change in the seat pan centre of pressure location in the anterior–posterior direction as exposure increased. There was also a significant gender-by-task interaction in seat pan centre of pressure ( $p = .020$ ). During the driving condition, women sat more anteriorly on the seat pan than men. During the typing task, there was no change in the anterior–posterior centre of pressure position on the seat pan between men and women. There were no significant differences in the anterior–posterior centre of pressure location attributed to task, but women sat more forward on the seat pan than men across both tasks ( $p = .048$ ) and both genders migrated their centre of pressure to a

more anterior position on the seat pan later in the simulation ( $p = .044$ ). There was also a significant ( $p < .001$ ) time-by-task interaction in the medio-lateral direction of seat pan centre of pressure (Figure 5b). As the length of MDT use increased, participants sat more to the right side of the seat. As driving exposure increased, there was no change in the seat pan centre of pressure in the medio-lateral direction. The seat pan centre of pressure exhibited a significant shift to the right side, towards the MDT location, during the typing task ( $p < .001$ ) and after 2 h of prolonged exposure ( $p < .001$ ) (Figure 5b).

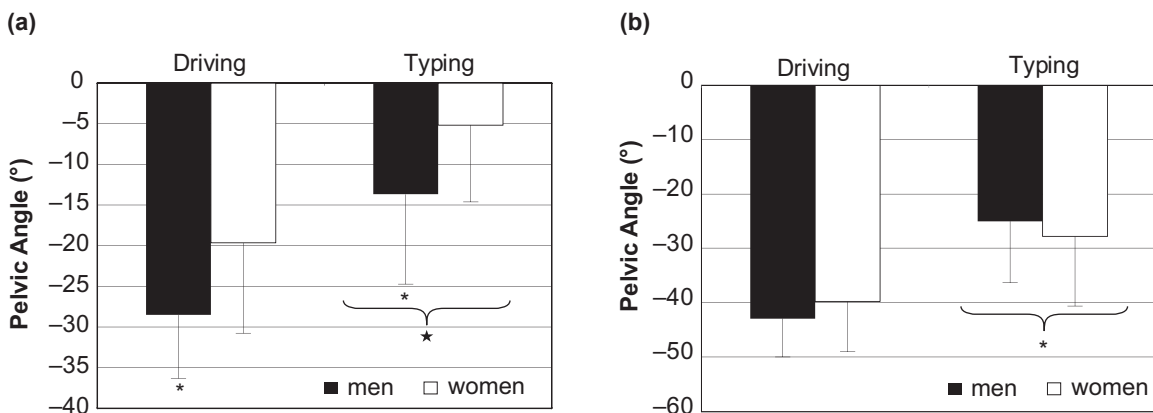
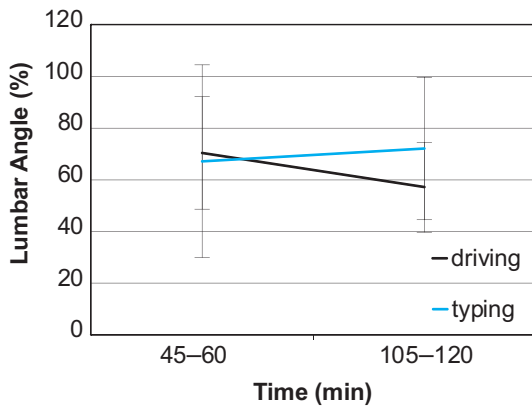
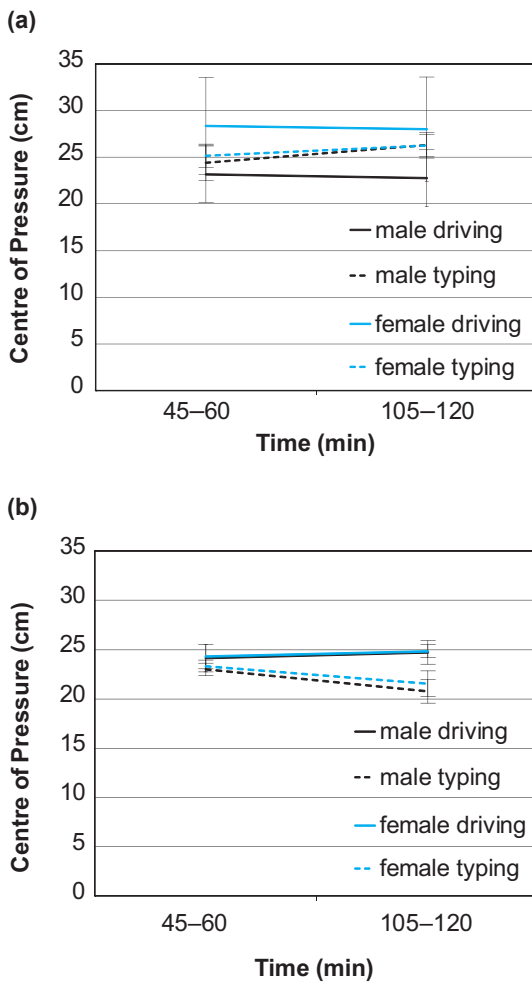


Figure 3. Average pelvic angles task: (a) angle with respect to vertical, (b) angle with respect to upright standing posture. Notes. \* = significant difference ( $p = .05$ ) between genders; \*\* = significant difference between tasks ( $p = .05$ ).



**Figure 4. Lumbar angles averaged by time point across gender normalized to each participant’s maximum flexion for the 2 tasks evaluated, driving and driving mixed with mobile data terminal (MDT) use.**



**Figure 5. Average seat pan centre of pressure: (a) anterior–posterior direction, values approaching zero represent the posterior aspect of seat pan, (b) medio-lateral direction, values approaching zero represent the right side of the seat pan.**

#### 4. DISCUSSION

The introduction of a computer interface with representative usage patterns significantly changed discomfort scores, pelvic posture and lumbar postural responses over prolonged driving when compared to driving alone. These findings suggest that introducing secondary tasks into a driving environment may increase the potential for pain reporting and time-varying response to increased lumbar flexion. Secondly, women reported similar levels of discomfort, but sat with less pelvic rotation and further forward on the seat pan.

The typing task produced a time-by-task interaction in lumbar flexion–extension postures and there was a reduction in posterior pelvic rotation. Anterior rotation of the pelvis is associated with increasing lordotic postures, which are thought to aid injury prevention [9]. During natural standing, women’s pelvic inclinations are 10° more anteriorly rotated and more lordotic than men’s [8]. During simulated nonoccupational driving, it has been shown that men have more extended trunk and elbow postures, but no significant gender differences in lumbar or pelvic postures [8]. There was a task-by-time interaction, where lumbar angles significantly decreased over the course of the driving condition, whereas lumbar angles increased over time during the typing condition. A recent prolonged driving study reported a significant time-by-gender interaction, where women had greater lumbar flexion in the second hour of the simulation than men [20]. However, the addition of on-body police equipment and MDT use have an effect on driving postures.

Previous investigations examining nonoccupational driving have found lower values of pelvic angles than the current investigation [8, 20]. After 1 h of exposure to prolonged driving, pelvic angles with respect to upright standing were 35.8° (*SD* 8.1°) in women and 35.1° (*SD* 6.2°) in men [8]. Similar values were found in a recent study involving 2 h of prolonged driving exposure with 29.0° (*SD* 10.5°) in women and 30.0° (*SD* 8.5°) in men [20]. In both studies, these angles represent posterior rotation of the pelvis in nonoccupational driving. The current investigation found greater average posterior pelvic inclination angles during

driving than in previous studies with  $39.8^\circ$  ( $SD$   $9.2^\circ$ ) and  $43.0^\circ$  ( $SD$   $7.0^\circ$ ) in women and men, respectively. This suggests that the duty belt and protective vest worn by officers alter baseline sitting postures from what is typically adopted in driving. Furthermore, a gender difference in pelvic postures with respect to the vertical was found in the current investigation with  $19.6^\circ$  ( $SD$   $11.1^\circ$ ) and  $28.5^\circ$  ( $SD$   $7.7^\circ$ ) of pelvic posterior rotation in women and men, respectively. These gender differences were not found in a previous investigation with  $13.1^\circ$  ( $SD$   $6.1^\circ$ ) in women and  $19.9^\circ$  ( $SD$   $7.1^\circ$ ) in men [20]. This suggests that the equipment worn by officers require a greater degree of pelvic rotation when compared to prolonged driving without equipment, especially among men.

Female participants sat more forward on the seat compared to men across tasks. This differs from the results of previous simulated driving studies without a typing task and without police equipment that have shown no difference in position on the seat pan between genders [8, 20]. However, women have been shown to sit with a more upright posture in office chairs and closer to the front of the seat pan [18]. The alteration of pelvic posture in women is most likely attributable to the duty belt worn while driving. Since women were on average 30 kg lighter than men, they would have been less able to compress the seat back foam and the focal pressure of the duty belt may have prevented posterior pelvic rotation.

There are several limitations in the quantification of lumbar and pelvic angles during prolonged seated exposures. Line-of-sight issues caused by the seat back of the chair prevented direct measurement of axial rotation of the spine with optical or electromagnetic kinematic motion capture systems that require larger on-participant instrumentation. The study was completed in a laboratory environment at room temperature. Professional drivers are exposed to a variety of conditions and seasonal weather. The addition of winter outdoorwear, a seat belt and a contained vehicle environment may further influence postures or discomfort.

The current investigation is the first attempt to examine the impact of how computer use can affect discomfort and postures when used in con-

junction with prolonged occupational driving. The impact of the location of the MDT has previously been examined from a biomechanics perspective evaluating the muscular and postural demands and it has been demonstrated that only modest improvements could be achieved due to the space constraints dictating the physical location of one-piece MDT units [19]. The relocation of the MDT was insufficient to reduce musculoskeletal discomfort and all tested configurations required similar shoulder elevation and low-back postures [19]. The results of this study demonstrated that MDT use in conjunction with driving increased discomfort in the neck, left shoulder, midback, low back and pelvis, lumbar angles became more flexed later in the prolonged exposure and the pelvis was significantly less posteriorly rotated compared to driving alone. The different postural and discomfort responses to prolonged driving compared to prolonged driving in conjunction with a typing task suggest different loading and muscular recruitment patterns. The results of the study provide insight into the biological processes that lead to low-back pain from prolonged sitting, especially the time-varying increases in lumbar spine flexion when a driver is using a computer as a secondary task, making postures more extreme and further away from a neutral spine posture. Further, the results have practical application in an ergonomic intervention for mobile officers exposed to prolonged driving indicating that usage patterns, location of the MDT, and time-varying responses should be considered in future design iterations. The growth of in-vehicle computer use by several industrial sectors coupled with the implication for increased discomfort and negative changes in lumbar spine and pelvic postures warrants consideration in the design and organization of vehicle work environments.

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