Applied Ergonomics 108 (2023) 103946

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Assessment of challenges in patrol vehicles and with equipment among law enforcement officers

Hongwei Hsiao [a,b,*]

[a] Texas A&M University, Corpus Christi, TX, USA
[b] National Institute for Occupational Safety and Health, Morgantown, WV, USA

ARTICLE INFO

Keywords:
Police
Vehicle equipment
Duty belts

ABSTRACT

Understanding the challenges Law Enforcement Officers (LEOs) have encountered with their vehicle and equipment and the correlation between equipment configuration and LEO body dimensions is critical for improving vehicle/equipment specifications to better accommodate today's LEOs. 974 LEOs participated in a study on their vehicle, equipment, and body measurements at 12 sites across the U.S. 88% participants reported discomfort/pain at the end of a shift. The most affected body areas were the lower back and hips. Handguns, radios, and handcuffs on duty belt and seat adjustment were associated with the discomfort/pain. 41% LEOs identified inadequate seat adjustment. Stature, buttock-popliteal length, eye height (sitting), knee height (sitting), shoulder-grip length, popliteal height, sitting height, hip breadth, and body weight were key parameters associated with seat adjustment needs. A third of officers experienced neck pain associated with the use of in-vehicle mobile data terminals and more fore/aft adjustment was needed.

1. Introduction

Vehicles are the workplace where patrol law enforcement officers (LEOs) spend significant portions of their workday (Mitsopoulos-Rubens et al., 2009). LEO vehicles typically are modified from existing lines of commercial vehicles, and most are modified by manufacturers or specialized companies (Kissiah, 2022; Grabianowski, 2022; Chavez, 2017). These cars are remodeled with enhanced alternators, suspensions, battery power, and engines. A full "makeover" also includes an array of electronics and safety gear, such as radios, dash cameras, mobile data terminals (MDTs), speed detectors, and seats which can accommodate officers who carry guns, handcuffs, and batons (Fig. 1). All the equipment takes up valuable space within the vehicle and can alter officer-equipment interface dynamics.

LEOs were reported to be on average larger in body dimensions than the civilian population (Hsiao et al., 2021). The makeover of vehicles from commercial vehicles which are designed based on civilians' body dimensions, compounded with the abovementioned additional safety equipment and protective gear (e.g., MDTs, dash cameras, speed detectors, duty belts, and armors), can aggregate safety and health challenges for LEOs. Random sample surveys have reported that the prevalence of lower back pain among patrol LEOs were in the range of 54.5%–92.6% (Brown et al., 1998; Arts, 2006; Mitsopoulos-Rubens et al., 2009). Design improvements of vehicle console space, vehicle ingress/egress, MDTs, and LEO body-worn equipment may result in reduced LEO fatigue, pain, or injury (McKinnon et al., 2011, 2014; Saginus et al., 2011; Saginus and Marklin, 2013). Understanding the association among the body pain, vehicle equipment setup, and body dimensions is necessary to effectively implement the design improvements.

While several studies have associated LEO discomfort in lower back and hip with duty belt items (e.g., handguns, radios, and handcuffs) (Arts, 2006; NIOSH et al., 2020), MDT use (Donnelly et al., 2009), and body armors (Burton et al., 1996), most survey studies in the literature about LEO body pain/discomfort were small-scale or random-sample (unstratified) surveys and did not cover the differences among LEOs, such as demographic and anthropometric characteristics. In addition, literature showed inconsistent results on LEO prevalence of lower back pain as compared to the general population (Brown et al., 1998; Arts, 2006; Shmagel et al., 2016), possibly due to small local samples from these studies. A larger-scale systematic national assessment with LEOs using stratified samples would provide an opportunity to deepen our understanding of challenges LEOs have encountered with their vehicles and equipment as well as the correlation among body discomfort/pain,

* Texas A&M University, Corpus Christi, 6300 Ocean Dr., Corpus Christi, TX, 78412, USA.
E-mail address: hongwei.hsiao@tamucc.edu.

https://doi.org/10.1016/j.apergo.2022.103946
Received 5 August 2022; Received in revised form 4 October 2022; Accepted 17 November 2022
Available online 28 November 2022
0003-6870/Published by Elsevier Ltd.

equipment configuration, and LEO body dimensions, which would offer more practical design solutions.

1.1. *Objective*

The study aimed to quantify the state of user-vehicle and user-equipment (i.e., handguns, radios, handcuffs, MDTs, duty belts, etc.) interfaces and the association among LEO body discomfort, LEO demographics, and LEO anthropometric characteristics for vehicle/equipment design improvement. It was hypothesized that (1) LEO body discomfort/pain was associated with vehicle equipment use, LEO demographics, and body dimensions, and (2) more fore/aft and up/down seat and MDT adjustments were needed for LEOs, as reported by LEOs for the vehicle they used most often, and were associated with LEO sex, stature, weight, and buttock-popliteal length. This study is the first national stratified study on LEO anthropometry and experimentally determined the key body dimensions for LEO vehicle and equipment configuration, which paved the way for better LEO vehicle and equipment design to advance LEO safety and wellbeing.

2. Methods

2.1. *Participants*

A total of 756 male and 218 female LEOs participated in the study. Their demographic information was recorded (Table 1; Hsiao et al., 2021) and anthropometric dimensions (Table 2, Fig. 2) relevant to LEO vehicle and equipment design were measured. They also answered 13 survey questions relevant to the state of LEO vehicle use, vehicle-user interface, and safety gear accommodation. The LEO sample was based on the geographic density of racial/ethnic distributions, calculated from the 2010 U.S. Census by four census regions (U.S. Census Bureau, 2012). The research protocol, questionnaire, and participant consent form were approved by the U. S. Office of Management and Budget (OMB #0920–1232) and the National Institute for Occupational Safety and Health (NIOSH) Institutional Review Board (IRB #14-DSR-02XP).

2.2. *Procedure*

Upon arrival to one of the 12 national LEO anthropometry study sites (Hsiao et al., 2021), each officer read and signed a consent form to participate in the study. Each participant had the opportunity to ask questions and completed a demographic data form which comprised sex, age, race/ethnicity, years of service, and occupational specialty. Their

Table 1
Participants by racial/ethnic group, sex, and age (Hsiao et al., 2021).

Item	Variable	Application for LEO vehicle cab and equipment arrangement	Without gear	With uniform
1	Bideltoid Breadth, Sitting	Seat back width	X	
2	Buttock-Knee Length	Dashboard-seat/seat back clearance	X	
3	Buttock-Popliteal Length	Seat depth	X	
4	Chest Breadth	Middle seat back width	X	
5	Chest Depth	Driving wheel clearance	X	
6	Elbow Rest Height+	Seat arm rest height	X	
7	Eye Height, Sitting	Wind shield height	X	
8	Hip Breadth, Sitting	Seat pan width	X	
9	Kee Height, Sitting	Driving wheel/ dashboard clearance	X	
10	Popliteal Height+	Seat height	X	
11	Sitting Height	Cruiser cab ceiling height	X	
12	Stature	Egress configuration	X	
13	Thumbtip Reach	Control panel reach	X	
14	Waist Breadth, Sitting	Space between arm rests	X	
15	Waist Circumference at Omphalion	Driving wheel clearance	X	
16	Weight (kg)	Overall vehicle workspace	X	
17	Body Mass Index (BMI)	Overall vehicle workspace	X	
18	Abdominal Extension Depth, Sitting	Driving wheel clearance		X
19	Acromion-Trochanter Surface Length, Sitting	Seatbelt (shoulder belt)		X
20	Bi-trochanter Surface Length, Sitting	Seatbelt (lap belt)		X
21	Shoulder-Grip Length	Equipment control		X
22	Thigh Clearance	Driving wheel clearance		X

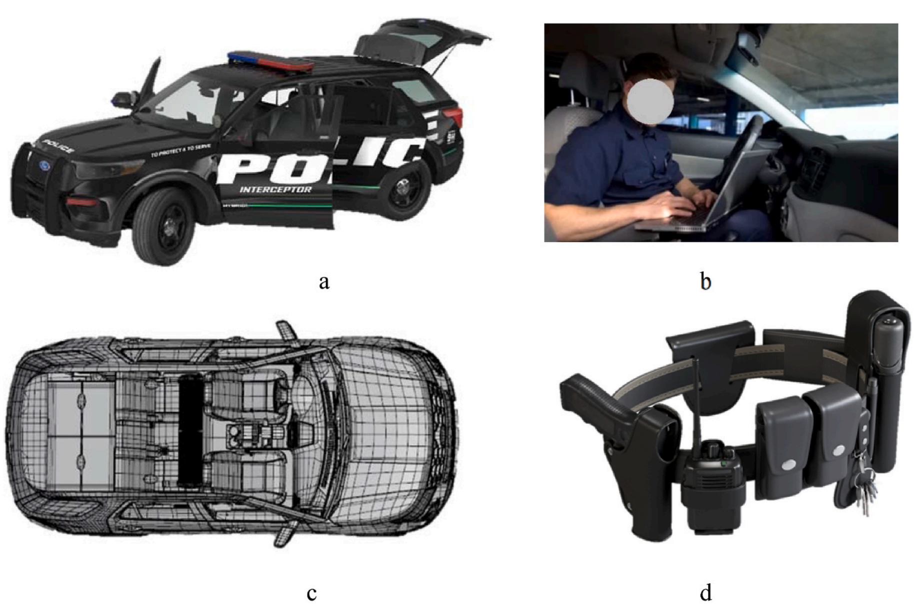

Fig. 1. A full police vehicle may include an array of electronics (1a) and safety gear, such as radios, dash cameras, mobile data terminals (1b), speed detectors, and seats (1c) which can accommodate officers who carry guns, handcuffs, and batons in a duty belt (1d) (Picture credits: Turbosquid.com and Shutterstock).

Table 2
Anthropometry relevant to LEO vehicle space and equipment configuration (Hsiao et al., 2022).

Race/ethnicity		White N = 685						Black N = 124		Hispanic/Other N = 165		Total
Sex		Males			Females			Males	Females	Males	Females	
Age		18–34	35–44	≥45	18–34	35–44	≥45	≥18	≥18	≥18	≥18	
Stratified samples		188	183	172	52	62	28	93	31	120	45	974
Total	Men	543						93		120		756
	Women				142				31		45	218

+: The Elbow Rest Height and Popliteal Height include a 10-mm addition to account for adjustment for compressed measurements.

body dimensions (Table 2) and 3-dimensional body scans were then measured by four anthropometry data collection specialists. The 3-dimensional body scan data were reported in a separate paper (Hsiao et al., 2022).

The participant was then given an iPad to review and answer 17 questions which assessed the state of their LEO vehicle equipment, vehicle-user interface, and protective gear fitting. Four of the 17 questions were relevant to body armor fit which will be reported in a separate article on "LEO Body Armors Fit and Comfort." Thirteen of the 17 questions were directly related to patrol vehicle use and are included in this article (Table 3).

After completing the body measurements, 3-dimensional scans while standing and seated within a Cyberware WBX 3-D whole-body scanner (Cyberware Inc., Monterey, CA), and survey questions, the participants were reimbursed for their time and dismissed.

3. Results

3.1. Demographic information and anthropometry

Participant demographics by racial/ethnic group, sex, age is summarized in the Methods section (Table 1). The mean years of LEO service was 12.8 for men and 10.7 for women. The longest-serving officer had completed 42 years of service. While 28.7% of participants had 5 or less years of service, 34.8% of the LEOs had 16 or more years of experience (Table 4). More male officers (37.2%) had served 16 years or more than female officers (26.6%) (Pearson $\chi^2_{974, 1} = 8.32$, p = 0.003).

Body dimensions relevant to LEO vehicle and equipment are summarized in Table 5. It is rare that sample acquisition exactly matches a sampling plan. A statistical weighting method can be utilized to apply the ratio of the actual sample to the target sample for each individual measured value to represent the population of interest (Hsiao et al., 2021). Since our sample outcomes by sex, racial/ethnic, and age group are very close to those of the original sampling plan, the unweighted and weighted data would be comparable in 1–3 mm in means. We elected to use unweighted data in this report for simplicity. The results indicate that female officers have a significantly larger mean of hip breadth (sitting) than male officers. No significant difference was found between men and women for elbow rest height (sitting). Male officers have a larger mean than female officers for the remaining 20 dimensions (Table 5).

3.2. LEO work hours and vehicle use

Most officers (84.7%) worked either an 8- or 10-h shift, while some worked part time, and 3.1% worked a 12-h shift. The average shift duration was 9.2 h, of which 5.4 h was spent in the vehicle. During their shifts in the vehicle, 55.1% of LEOs entered and exited vehicles 16 times or more in a shift (Table 6) – more for men than women (58.3% vs. 44.1%; Pearson $\chi^2_{897, 1} = 12.8$, $p < 0.001$). Only 10% got in and out 5 times or fewer.

The make and model of vehicles used by the LEOs varied. The most frequently used makes were Ford for 595 officers (66.4%), Chevrolet for 148 officers (16.6%), and Dodge for 115 officers (12.8%). Thirty-six officers used other makes; two officers did not have an assigned vehicle; and 78 officers did not respond to this question (N = 896; 78 missing) (Table 7). Of the 595 Ford vehicles, 303 (50.9%) were the Explorer model and 96 (16.1%) were Crown Victoria. Of the 148 Chevrolet vehicles, 70 (47.3%) were the Tahoe model, and of the 115 Dodge cruisers, 98 (85.2%) were the Charger model (Fig. 3). The model years of vehicles (N = 893; 81 missing) ranged from 1990 to 2019 with a median of 2015 and mean of 2014 which are considered reasonably new since the data collection was conducted in 2018 and 2019.

3.3. Vehicle-user interface

3.3.1. Vehicle seat adjustments

For the vehicles used by the participating officers (N = 894; 80 missing), the range of seat adjustment was adequate for 59.3% of the participants (Table 8). For those who felt that the seat adjustment was inadequate (40.7%), more adjustments were needed: 19.0% in the fore/aft direction, 12.9% in the up/down direction, and 8.8% in both directions. No significant difference was detected between male and female officers on the *overall need* for seat adjustments ($\chi^2_{894, 1} = 1.76$, p = 0.18). However, for the inadequate seat adjustment situation, male officers desired more fore/aft adjustments, while female officers wanted more up/down adjustments as well as both up/down and fore/aft adjustments ($\chi^2_{364, 2} = 12.0$, p = 0.0025).

Significant differences were found among race/ethnicity groups on the overall need for seat adjustments ($\chi^2_{894, 2} = 28.6$, $p < 0.0001$). About 35.1% of White and 50% of Hispanic/Other LEOs reported inadequate seat adjustments, and 58.2% of Black LEOs indicated a need for additional seat adjustments. For those who felt that the seat adjustment was inadequate (40.7%), no significant difference in the distribution of seat adjustment needs (i.e., in the fore/aft, up/down, and both fore/aft and up/down directions) were identified among ethnicity groups ($\chi^2_{364, 4} = 3.39$, p = 0.495).

The abovementioned data regarding the association between sex and seat adjustment direction as well as the correlation between ethnicity and overall seat adjustment needs lead to the root impact of body dimensions on seat adjustment needs. Those who needed more *fore/aft* seat adjustments had a greater mean of all body dimensions listed in Table 2 (except for Elbow Rest Height) than the group who reported satisfaction with seat adjustments. Those who needed more up/down seat adjustments had a smaller mean of body dimensions than the group who reported satisfaction with seat adjustments for 7 dimensions: Buttock-Popliteal Length, Eye Height (Sitting), Knee Height (Sitting), Popliteal Height, Sitting Height, Stature, and Shoulder-Grip Length. They however had a larger mean of Hip Breadth (Sitting) and Body Mass Index (BMI).

Using stature and buttock-popliteal length as examples, those who needed more fore/aft seat adjustments had a greater mean of stature (Mean = 1779 mm; Standard Error = 6.2 mm) than the group who reported satisfaction with seat adjustments (Mean = 1745 mm; Standard Error = 3.5 mm) (all pairs Tukey-Kramer HSD, $p < 0.001$), and the group who reported satisfaction with seat adjustments had a greater mean of stature than those who needed more up/down seat adjustments (Mean = 1720 mm; Standard Error = 7.7 mm) ($F_{893, 3} = 12.37$, $p < 0.001$; all

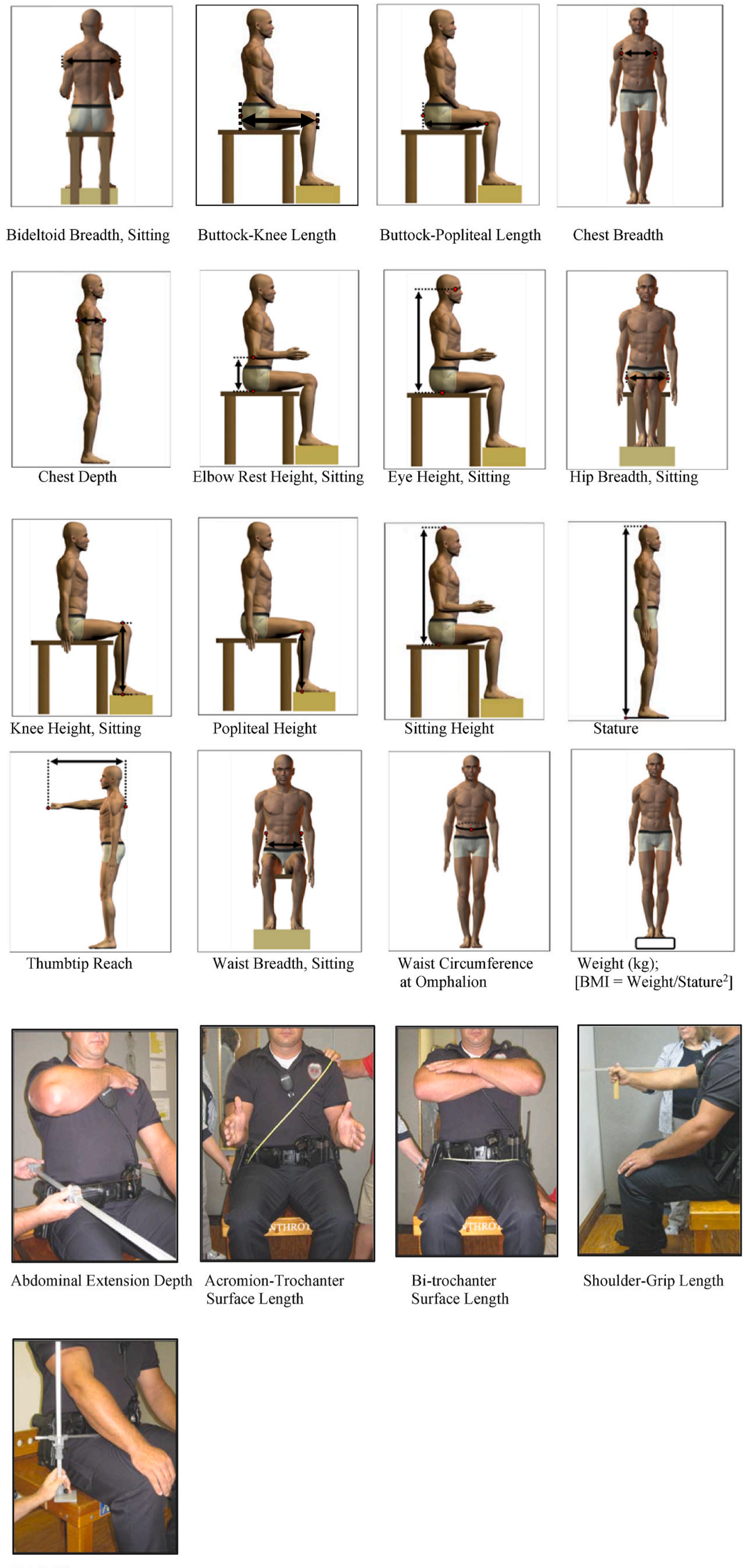

Fig. 2. Body dimensions relevant to LEO vehicle cab and equipment design (Hsiao et al., 2021).

pairs Tukey-Kramer HSD, p = 0.0194) (Fig. 4).

Those who needed more *fore/aft* seat adjustments or more *both fore/aft and up/down* adjustments had a greater mean of buttock-popliteal length (Mean = 522 mm, Standard Error = 2.3 mm; Mean = 520 mm, Standard Error = 3.4 mm) than the group who reported satisfaction with seat adjustments (Mean = 508 mm; Standard Error = 1.3 mm) (all pairs Tukey-Kramer HSD, p < 0.001 for both pairs). The group who reported the need for just *up/down* seat adjustments had a smaller mean of buttock-popliteal length (Mean = 501 mm; Standard Error = 2.8 mm) comparing to the group who reported satisfaction with seat adjustments but was not at a significant level (all pairs Tukey-Kramer HSD, p = 0.1711) (Fig. 5).

3.3.2. Body discomfort/pain and equipment use

About 88% of officers reported some discomfort/pain at the end of a shift (Table 9). More portion of females (92.6%) encountered some discomfort/pain than males (86.6%) (Pearson $\chi^2_{895,\ 1} = 5.41$, p = 0.02). The most affected body areas were the lower back and hip (Table 9). The percentages of affected body parts do not sum to 100%, as some officers reported more than one discomfort body area.

One reason for discomfort in the lower back and hip can be attributed to the duty belt and various equipment carried on it. About 76.3% LEOs reported that duty belts cause pain or discomfort while seated in the vehicle. More female LEOs (85.2%) reported that duty belts caused pain than male LEOs (73.7%) (Pearson $\chi^2_{890,\ 1} = 11.6$, p = 0.0007). Body dimensions did not play a significant role in the reported pain; waist circumference ($F_{889,\ 1} = 2.78$, p = 0.096), body weight ($F_{889,\ 1} = 2.34$, p = 0.13), and waist breadth ($F_{889,\ 1} = 1.61$, p = 0.20) do not correlate with the pain caused by duty belts.

Table 10 shows the equipment carried by each officer on his/her

Table 3
Survey questions related to patrol vehicle use.

1. How long is a normal (not overtime) shift? [(hours)]
2. How long do you spend in your vehicle during a normal shift? [(hours)]
3. How often (approximately) do you get in and out of your vehicle during that shift?
   [0-5] [6-10] [11-15] [16-20] [21-25] [26-30] [>30]
4. What make/model is the vehicle you use <u>most</u> often? [Make: Model:]
5. What is the year of the vehicle you use most often? [(20XX)]

Please answer the remaining questions with respect to THAT vehicle and when you are wearing your body armor and duty belt.

6. Is the seat adjustment adequate? [Y] [N]
   If N, how should it be improved?
   - ☐ More up/down adjustment needed
   - ☐ More fore/aft adjustment needed
7. Are there specific areas of your body that are uncomfortable or painful at the end of a shift?
   If Y: [Y] [N]
   - ☐ Neck
   - ☐ Shoulders
   - ☐ Chest
   - ☐ Abdomen
   - ☐ Upper back
   - ☐ Lower back
   - ☐ Hips
   - ☐ Knees
   - ☐ Ankles
   - ☐ Other:
8. Do you have neck pain from using the mobile data terminal (MDT)? [Y] [N]
   Can the location of the MDT be adjusted to your preference? [Y] [N]
   If No:
   - ☐ Insufficient up/down range
   - ☐ Insufficient fore/aft range
   - ☐ No adjustment possible
   - ☐ No MDT

9. If your vehicle has a permanently mounted radio, where is it located?
   - ☐ Dashboard
   - ☐ Console
   - ☐ Ceiling
   - ☐ Floor
   - ☐ No permanently mounted radio

10. Which of the following do you carry on your duty belt?
    - ☐ Handgun
    - ☐ Radio
    - ☐ Handcuffs
    - ☐ Pepper spray
    - ☐ Taser
    - ☐ Flashlight
    - ☐ Ammunition pouch
    - ☐ Baton
    - ☐ Key holder
    - ☐ Disposable gloves
    - ☐ Knife
    - ☐ First Aid kit

11. Does any item on the duty belt cause pain or discomfort while you are seated in the vehicle? [Y] [N]

    If Y:
    - ☐ Handgun
    - ☐ Radio
    - ☐ Handcuffs
    - ☐ Pepper spray
    - ☐ Taser
    - ☐ Flashlight
    - ☐ Ammunition pouch
    - ☐ Baton
    - ☐ Key holder
    - ☐ Disposable gloves
    - ☐ Knife
    - ☐ First Aid kit

12. Do you use a thigh/leg holster? [Y] [N]

13. Do you use a seat belt extender? [Y] [N]

Table 4
Law enforcement officer years of service.

Years	Total		Males		Females	
	N	%	N	%	N	%
0–5	280	28.7	199	26.3	81	37.2
6–10	150	15.4	117	15.5	33	15.1
11–15	205	21.0	159	21.0	46	21.1
16–20	141	14.5	119	15.8	22	10.1
21–25	122	12.5	99	13.1	23	10.6
26–30	55	5.7	44	5.8	11	5.0
≥31	21	2.2	19	2.5	2	.9
Total	**974**	**100**	**756**	**100**	**218**	**100**
0–15	**635**	**65.2**	**475**	**62.8**	**160**	**73.4**
≥16	**339**	**34.8**	**281**	**37.2**	**58**	**26.6**

duty belt as well as whether that particular item caused discomfort when seated in the vehicle. Handguns, radios, and handcuffs were the leading equipment associated with seated discomfort/pain.

If a LEO wore bulky gear or body armor, a thigh holster holding his/her gun down further from the equipment would allow the LEO an easier draw stroke. Also, a thigh holster may allow him/her an easier draw from the seated position. On the other hand, while a LEO is moving, his/her holster is moving as well, which requires the user to modify his or her movements in order to have successful draw stroke. About 7.5% participants (7.4% for men and 7.8% for women) in the survey used a thigh holster (Table 11).

3.3.3. *Seat belt extenders*

Seat belt extenders are a vehicle accessory which help ensure the safety or comfort of plus-sized persons. This LEO equipment survey showed that 4.6% of LEOs (5.1% for men and 3.0% for women) used seat belt extenders in their vehicles (Table 12), which means that the current seat belt length or configuration may not be sufficient for about 5% of LEOs. The difference in percentage in the use of seat belt extenders between men and women is not statistically significant (Pearson $\chi^2_{894,\,1} = 1.06$, p = 0.21).

Table 5
Body dimensions relevant to LEO vehicle and equipment design (Weight in kg; body Mass index in no unit; all other values in mm).

Dimension	Males				Females				Sig Diff
	N	Mean	Std Dev	Std Error	N	Mean	Std Dev	Std Error	
Bideltoid Breadth, Sitting	756	514	33	1.2	218	451	28	1.9	Yes
Buttock-Knee Length	756	631	34	1.3	218	600	32	2.1	Yes
Buttock-Popliteal Length +10	756	515	30	1.1	218	492	27	1.8	Yes
Chest Breadth	756	372	36	1.3	218	320	30	2.0	Yes
Chest Depth	756	281	30	1.1	218	266	35	2.4	Yes
Elbow Rest Height, Sitting +10	756	254	29	1.1	218	247	26	1.7	NO
Eye Height, Sitting	756	810	34	1.2	218	760	31	2.1	Yes
Hip Breadth, Sitting*	756	401	33	1.2	218	417	40	2.7	Yes*
Knee Height, Sitting	756	567	30	1.1	218	521	26	1.8	Yes
Popliteal Height + 10	756	433	27	1.0	218	393	24	1.6	Yes
Sitting Height	756	930	35	1.3	218	875	31	2.1	Yes
Stature	756	1778	71	2.6	217	1651	63	4.3	Yes
Thumbtip Reach	756	831	49	1.8	218	758	41	2.8	Yes
Waist Breadth, Sitting	756	359	40	1.5	218	325	41	2.8	Yes
Waist Circumference (Omp.)	756	1026	130	4.7	218	904	126	8.5	Yes
Weight (kg)	756	95.5	17.5	0.6	218	74.3	13.6	0.9	Yes
Body Mass Index (BMI)	756	30.2	4.8	0.2	217	27.3	4.6	0.3	Yes
Abdom. Exten. Depth, Sitting (with uniform)	756	351	46	1.7	218	316	39	2.6	Yes
Acromion-Trochanter Surface Length, Sitting (with uniform)	755	837	54	2.0	218	789	47	3.1	Yes
Bi-trochanter Surface Length, Sitting (with uniform)	756	719	63	2.3	218	670	60	4.1	Yes
Shoulder-Grip Length (with uniform)	756	804	41	1.5	218	740	38	2.6	Yes
Thigh Clearance (with uniform)	756	198	17	0.6	218	181	17	1.2	Yes

+10: 10 mm was added to the measurements of Buttock-Popliteal Length, Elbow Rest Height (Sitting), and Popliteal Height to reflect the fact that the dimensions were measured when the body components were compressed and a clearance for the body area is needed.
*: Female officers have a significant larger mean of hip breadth (sitting) than male officers. No significant difference was found between men and women for Elbow Rest Height (sitting). Male officers have a larger mean than female officers for the remaining 20 dimensions. Two-tail t-tests at significance level of 0.05 were performed, with p = 0.05/22 = 0.0023 for 22 paired comparisons between men and women (z = 2.83).

Table 6
Law enforcement officers in/out of the vehicle per shift.

Number of Times In/Out	Total		Males		Females	
	N	%	N	%	N	%
0–5	91	10.1	53	7.6	38	18.6
6–10	181	20.2	139	20.1	42	20.6
11–15	131	14.6	97	14.0	34	16.7
16–20	154	17.2	125	18.0	29	14.2
21–25	100	11.2	81	11.7	19	9.3
26–30	115	12.8	92	13.3	23	11.3
>30	125	13.9	106	15.3	19	9.3
Subtotal	897	100	693	100	204	100
Missing	77		63		14	
Total	974		756		218	
0–15	403	44.9%	289	41.7%	114	55.9%
16–30 or more	494	55.1%	404	58.3%	90	44.1%
Subtotal	897		693		204	

Table 7
Law enforcement officer vehicles most often used.

Make of the Vehicles	Total		Males		Females	
	N	%	N	%	N	%
BMW	1	0.1	1	0.1	0	0.0
Chevrolet	148	16.6	119	17.1	29	14.3
Dodge	115	12.8	90	13.0	25	12.4
Ford	595	66.4	458	66.0	137	67.8
GMC	5	0.5	5	0.7	0	0.0
Harley Davidson	1	0.1	0	0.0	1	0.5
Honda	5	0.6	3	0.4	2	1.0
Jeep	5	0.6	3	0.4	2	1.0
Kia	1	0.1	0	0.0	1	0.5
Nissan	4	0.4	3	0.4	1	0.5
Toyota	14	1.6	11	1.6	3	1.5
No Vehicle	2	0.2	1	0.1	1	0.5
Subtotal	896	100	694	100	202	100
Missing	78		62		16	
Total	974		756		218	

Body weight is a factor for the need of a seat belt extender ($t = 1.96$, $p = 0.0409$; Fig. 6). The group who used a seat belt extender has a greater mean of body weight (mean = 97.3 kg, standard error = 2.93 kg) than the counterpart group (mean = 90.8 kg, standard error = 0.64 kg).

3.3.4. *Mobile data terminal (MDT) and mounted radio*

About a third of officers (33.9%) experienced neck pain associated with the use of mobile data terminals mounted in the vehicle (Fig. 1b). More female LEOs (42.1%) encountered neck pain than male LEOs (31.5%) (Pearson $\chi^2_{892,\ 1} = 8.24$, $p = 0.004$).

More than a half (54.5%) of LEOs could not adjust the location of the MDT to their preference (including one case of no MDT available). Of them, 40.1% LEOs reported insufficient adjustment of their MDT; 14.3% had no adjustment function; and 0.1% had no MDT (Table 13). A greater proportion of female LEOs (60.6%) had a challenge to adjust the MDT to their preference than male LEOs (52.3%) (Pearson $\chi^2_{884,\ 1} = 3.81$, $p = 0.05$). Of the 354 responses on MDT adjustment needs (excluding MDTs with no adjustment), more LEOs desired additional *fore/aft* adjustment (39.6%) than *both fore/aft and up/down* adjustment (32.2%) and *up/down* adjustment (28.3%). There was no significant difference on the desired MDT adjustment between female and male LEOs (Pearson $\chi^2_{354,\ 2} = 0.92$, $p = 0.63$). In addition, no body dimensions were found to clearly associate with the need of MDT adjustment in different directions: buttock-knee length ($F_{353,\ 2} = 0.74$, $p = 0.53$), statute ($F_{353,\ 2} = 0.08$, $p = 0.92$), body weight ($F_{353,\ 2} = 0.0009$, $p = 0.99$), and thumbtip reach ($F_{353,\ 2} = 1.27$, $p = 0.28$). The limited available vehicle console space in fore/aft direction seems to be a challenge to LEOs, which requires innovative solutions.

Permanently mounted radios were affixed on the console for 79.4% of LEO responses (Table 14). Some radios were installed on the floor (8%) or dashboard (6.5%). No pain or discomfort associated with the radio mount location was reported by LEOs.

Fig. 3. Commonly used LEO vehicles (Pictures/models acquired from Turbosquid.com).

Table 8
Law enforcement officers vehicle seat adjustment evaluation.

Evaluation	Total		Males		Females	
	N	%	N	%	N	%
Inadequate Seat adjustment	**364**	**40.7**	**274**	**39.5**	**90**	**44.8**
More up/down adjustment needed	*115*	*12.9*	*79*	*11.4*	*36*	*17.9*
More fore/aft adjustment needed	*170*	*19.0*	*142*	*20.5*	*28*	*14.0*
Up/down & fore/aft adjustment needed	*79*	*8.8*	*53*	*7.6*	*26*	*12.9*
Adequate Seat adjustment	**530**	**59.3**	**419**	**60.5**	**111**	**55.2**
Subtotal	**894**	**100.0**	**693**	**100.0**	**201**	**100.0**
Missing	80		63		17	
Total	**974**		**756**		**218**	

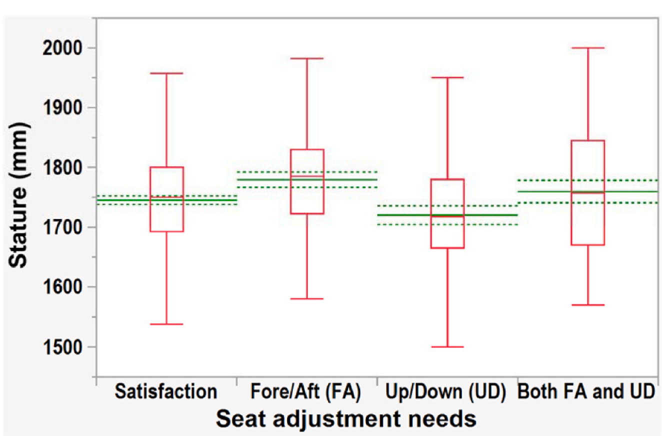

Fig. 4. Stature in means (solid green lines) and confidence intervals (CI) of means (dotted lines; 95% two-tail CI) by seat adjustment needs. The Box plots show maximum, upper quartile, median, lower quartile, and minimum values of stature of the four Seat Adjustment Needs groups. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

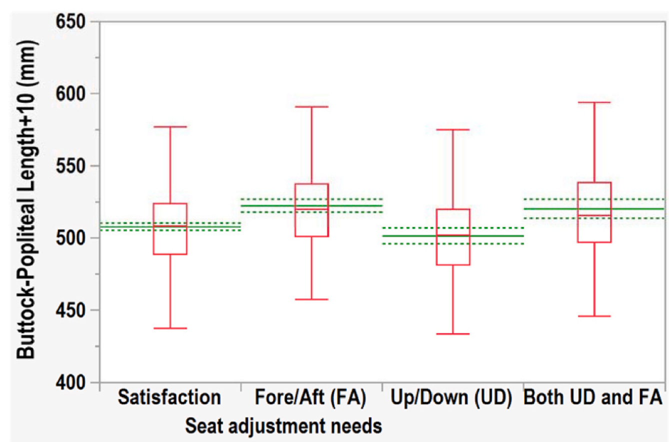

Fig. 5. Buttock-popliteal length in means (solid green lines) and confidence intervals (CI) of means (dotted lines; 95% two-tail CI) by seat adjustment needs. The Box plots show maximum, upper quartile, median, lower quartile, and minimum values of Buttock-Popliteal Length of the four Seat Adjustment Needs groups. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 9
Body area pain/discomfort among law enforcement officers.

Body Areas	Total		Males		Females	
	N	%	N	%	N	%
Neck	212	22.4	143	19.5	69	32.7
Shoulder	125	13.2	79	10.8	46	21.8
Chest	20	2.1	14	1.9	6	2.8
Abdomen	47	5.0	32	4.4	15	7.1
Upper Back	128	13.5	88	12.0	40	19.0
Lower Back	647	68.5	491	66.9	156	73.9
Hip	402	42.5	295	40.2	107	50.7
Knee	229	24.2	187	25.5	42	19.9
Ankle	72	7.6	63	8.6	9	4.3
Other	21	2.2	14	1.9	7	3.3

Table 10
Equipment carried by LEOs on their duty belts caused discomfort when seated in the vehicle.

Duty Belt Equipment	Total (N = 945; 29 missing)				Males (N = 734; 22 missing)				Females (N = 211; 7 missing)			
	Equipment		Seated Discomfort/Pain		Equipment		Seated Discomfort/Pain		Equipment		Seated Discomfort/Pain	
	N	%	N	%	N	%	N	%	N	%	N	%
Handgun	867	91.7	406	43.0	677	92.2	304	41.4	190	90.0	102	48.3
Radio	828	87.6	280	29.6	637	86.8	203	27.7	191	90.5	77	36.5
Handcuffs	867	91.7	244	25.8	672	91.6	172	23.4	195	92.4	72	34.1
Pepper Spray	773	81.8	61	6.5	587	80.0	46	6.3	186	88.2	15	7.1
Taser	545	57.7	146	15.4	419	57.1	112	15.3	126	59.7	34	16.1
Flashlight	752	79.6	134	14.2	579	78.9	90	12.3	173	82.0	44	20.9
Ammunition Pouch	826	87.4	123	13.0	643	87.6	108	14.7	183	86.7	15	7.1
Baton	584	61.8	168	17.8	447	60.9	124	16.9	137	64.9	44	20.9
Key Holder	480	50.8	12	1.3	375	51.1	9	1.2	105	49.8	3	1.4
Disposable Gloves	400	42.3	28	3.0	307	41.8	21	2.9	93	44.1	7	3.3
Knife	302	32.0	7	.7	236	32.2	4	.5	66	31.3	3	1.4
First Aid Kit	122	12.9	21	2.2	103	14.0	16	2.2	19	9.0	5	2.4

* The percentages do not total to 100%, as officers carried more than one item on the belt. Infrequently carried items were recorded but are not included in this table.

Table 11
Use of thigh holster among LEOs.

	Total		Male		Female	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Yes	67	7.5	51	7.4	16	7.8
No	828	92.5	640	92.6	188	92.2
Subtotal	895	100.0	691	100.0	204	100.0
Missing	79		65		14	
Total	974		756		218	

Table 12
Use of seat belt extender.

	Total		Male		Female	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Yes	41	4.6	35	5.1	6	3.0
No	852	95.4	655	94.9	197	97.0
Subtotal	893	100.0	690	100.0	203	100.0
Missing	81		66		15	
Total	974		756		218	

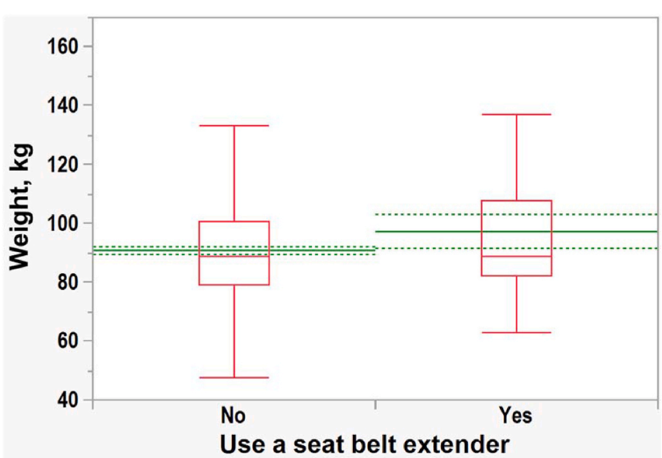

Fig. 6. Body weight is a factor for the need of a seat belt extender: weight in means (solid green lines) and confidence intervals (CI) of means (dotted lines; 95% two-tail CI) by the use (No or Yes) of a seat belt extender. The Box plots show maximum, upper quartile, median, lower quartile, and minimum values of body weight of the two seatbelt-extender use groups. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4. Discussion

4.1. *Demographic information, years of service, and anthropometry*

This study showed that 37.2% male officers and 26.6% female officers had served 16 years or more. Women made up 5.0% of LEOs in 1980 (Cordner and Cordner, 2011), 13% in 2011 (U.S. Census Bureau, 2012), and 17.6% in 2019 (U.S. Bureau of Labor Statistics, 2020). The increasing trend of females in patrolling occupations and longer career service for both male and female officers point to the need to revisit

Table 13
Law enforcement officers mobile data terminal adjustment.

Adjustment	Total		Males		Females	
	N	%	N	%	N	%
Sufficient adjustment possible	402	45.5	324	47.3	78	39.2
Insufficient up/down range	100	11.3	69	10.0	31	15.6
Insufficient fore/aft range	140	15.8	104	15.2	36	18.0
Insufficient up/down & fore/aft range	114	12.9	84	12.3	30	15.1
No adjustment possible	127	14.4	104	15.2	23	11.6
No MDT	1	.1	0	.0	1	0.5
Subtotal	884	100.0	685	100.0	199	100.0
Missing	90		71		19	
Total	974		756		218	

current in-vehicle equipment layout, vehicle seat adjustment, equipment configuration, and protective gear design for the safety and well-being of LEOs. This is particularly critical for vehicle seat design and adjustment and equipment layout in that female officers have a significant larger mean of hip breadth than male officers, and male officers have a larger mean for other dimensions than female officers.

This study revealed that male LEOs had a mean body mass index (BMI) of 30.2 (stand deviation = 4.8) and female LEOs had a mean BMI of 27.3 (stand deviation = 4.6). BMI is a screening tool used to identify individuals who are underweight, overweight, or obese. The World Health Organization (WHO) classified BMI into multiple categories: Underweight <18.5, Normal weight = 18.5–24.9, Overweight = 25–29.9, Obesity = 30–34.9, and Severe Obesity = 35 or greater (World Health Organization, 2022). Using the WHO scale, a sizable portion of both male and female LEOs would fall in the category of Overweight or Obesity. However, BMI is not a diagnostic tool and LEOs have a notable larger upper torso build as compared to the general population for both men and women (Hsiao et al., 2021). The larger LEO body dimensions and BMI have an important implication. LEO vehicles typically are modified from existing lines of commercial vehicles (Kissiah, 2022; Chavez, 2017) for power, electronic devices, and safety gear. Using the new LEO anthropometry data representing race/ethnicity, age, and sex distributions of the current law enforcement workforce rather than existing civilian anthropometry data for LEO vehicle and equipment design to better accommodate current LEOs is suggested.

4.2. LEO work hours, time in vehicles, and low back pain

The average LEO shift duration was 9.2 h and LEOs on average spent 5.4 h in their vehicles, which is consistent with a regional study (N = 476) that 75% of responders spent at least a half of their shift in vehicle (Mitsopoulos-Rubens et al., 2009). Moreover, more than 55% of LEOs entered and exited vehicles 16 times or more in a shift. While some LEO vehicles such as Ford Explorer and Chevrolet Tahoe may be considered upper scale vehicles in terms of console space, the long work hours in a "confined" area per shift, compounded with LEO body size and equipment use, represented a challenge for LEO well-being, including lower back pain, fatigue, and stress. This leads to the question on prevalence of lower back pain among LEOs as compared to the general population.

A Canadian police health services research survey of a random sample (N = 1002) reported that the prevalence of lower back pain since joining the law enforcement workforce (54.9%) was comparable with that of the general population (Brown et al., 1998). A U.S. County survey (N = 93) also did not find a significant difference in lower back pain experienced by LEOs (60.2%) and the county general population (60–90%) (Arts, 2006). The current *stratified* U.S. national study (N = 974) showed that 88% LEOs reported some discomfort/pain at the end of a shift with a major discomfort at the lower back and hip, which is greater than the prevalence rates of the general U.S. population of 13.1% (Shmagel et al., 2016) and 37% (National Center for Health Statistics, 2004). This stratified sampling survey (with a 91.4% response rate) provided a broader national perspective on LEO lower back pain prevalence than random sampling methods. Future stratified studies on occupational and non-occupational exposures of lower back pain risk among LEOs may further our understanding of LEO lower back pain to better protect LEO safety and well-being.

Table 14
Law enforcement officers location of permanently mounted radio.

Location	Total		Males		Females	
	N	%	N	%	N	%
Dashboard	58	6.5	40	5.8	18	9.0
Console	708	79.4	562	81.3	146	72.6
Ceiling	2	.2	1	.1	1	.5
Floor	71	8.0	54	7.8	17	8.5
Between seats	1	.1	1	.1	0	.0
No permanently mounted radio	52	5.8	33	4.8	19	9.5
Subtotal	892	100.0	691	99.9	201	100.1
Missing	82		65		17	
Total	974		756		218	

4.3. Body discomfort and duty belt

A sizable portion of the LEOs (86.5% males; 92.6% females) reported some discomfort/pain at the end of a shift, which is greater than that of a smaller county study (N = 93) for 60% (Arts, 2006) and a local survey (N = 52) for 48% (NIOSH et al., 2020). Duty belt items (handguns, radios, and handcuffs) were significant sources of discomfort as reported by all three studies, which are in line with a report that the edges of duty belts and gear caused discomfort and "short officers often find that the barrel of the gun presses downward into the car seat, resulting in an upward pressure of the belt or the grip of the weapon against the rib cage or body armor" (Czarnecki and Janowitz, 2003). The discomfort may be intensified with the increased time LEOs spent in vehicles (Gyi and Porter, 1998) and the increased gear weight of 10.9 kg for men and 9.2 kg for women (Hsiao et al., 2021). Some solutions were suggested to lessen the discomfort: (1) use of rounded and padded edges for duty belts, (2) use of moderately flexible nylon materials to replace the rigid leather belt, and (3) use of a belt with hook-and-loop closures allowing the length to be infinitely adjustable to the officer's girth to replace the older design which has adjustment holes of 30 mm apart for the buckle (Czarnecki and Janowitz, 2003).

There was no clear answer in the literature on whether carriage assist devices like suspenders and external duty vests (as an aid or replacement to duty belts) would reduce lower back and hip discomfort. A Canadian study (N = 27) reported that the level of discomfort or pain was lower with the use of a duty belt suspender than the use of a regular duty belt (Arnold, 2000). A smaller scale study indicated that greater discomfort was experienced at the lower back and hip while seated when highway patrol officers (N = 11) were wearing the duty belt compared to the external duty vest; however, use of an external duty vest alone did not eliminate discomfort (Filtness et al., 2014). Another study revealed that pressures in the lower back (N = 22) were reduced when wearing an external duty vest (compared to the use of a duty belt) whereas pressures in the upper back region increased (Larsen et al., 2019). A more detailed large-scale study on duty vest use associated with body discomfort as well as solutions to reduce LEO lower back risk exposure is warranted.

4.4. Mobile data terminal (MDT)

This study on the use of mobile data terminals revealed that less than a half (45.3%) of officers could adjust the location of MDTs to their preference. More females (42.1%) than males (31.5%) experienced neck pain associated with the use of mobile data terminals mounted in their vehicle. The need for increased up/down and fore/aft adjustment ranges was reported. Since MDT use represented over 13% of in-vehicle time activities performed by LEOs (McKinnon et al., 2011) and MDTs are becoming common and important equipment for LEO vehicles (Zahabi and Kaber, 2018), an integration of MDTs with the vehicle for improved LEO-MDT interface is deemed necessary for improving LEO safety and health. In fact, in a questionnaire survey (N = 58), MDT use was rated the greatest discomfort level among LEO equipment use (Donnelly et al., 2009). While some studies have suggested MDT locations in front of the driver (McKinnon et al., 2014) or near the steering wheel (Saginus et al., 2011; Saginus and Marklin, 2013) as the best in terms of subjective assessment and lower back stress estimation, others had a concern that locating the MDT close to the steering wheel might interfere with LEO interaction with the radio and control panel (Zahabi et al., 2020). Technical and cost challenges for alternative MDTs in LEO vehicles (e.g., head-up or wearable displays) and physical adjustment ranges for current MDTs for LEOs with diverse body dimensions remain to be addressed.

4.5. LEO vehicle seat adjustment and seat belt

This study found that seat adjustment was inadequate for 40.7% of LEOs. More adjustments were needed in the fore/aft direction for 19.0%, up/down direction for 12.9%, and in both fore/aft and up/down directions for 8.8% of LEOs. As compared to the LEOs who reported satisfaction with seat adjustments, the group who needed more fore/aft seat adjustments had a greater mean in body height, buttock-popliteal length, and 19 other dimensions (Table 2). The group who needed more up/down seat adjustments had a smaller mean of stature, buttock-popliteal length, eye height (sitting), knee height (sitting), popliteal height, sitting height, and shoulder-grip length; they however had a larger mean of hip breadth and BMI. LEO vehicle manufacturers and retrofitting companies can weigh these nine primary factors and LEO anthropometry data in their seat designs to better accommodate current LEOs.

Two body dimensions are relevant to seat belt length: Acromion-Trochanter Surface Length - sitting (shoulder belt) and Bi-Trochanter Surface Length - sitting (lap belt) (Fig. 2). The Acromion-Trochanter Surface Length - sitting (shoulder belt) is 837 $\pm$ 53 mm for men and 790 $\pm$ 47 mm for women (mean $\pm$ standard deviation). The Bi-trochanter Surface Length - sitting (lap belt) is 719 $\pm$ 63 mm for men and 672 $\pm$ 62 mm for women. The minimum belt web length for pelvic and upper torso restraint for men can be calculated as $(837 + 53 \times 3.1) + (719 + 63 \times 3.1) = 1001.3 + 914.3 = 1915.6$ mm, where 837 and 719 are means of the Acromion-Trochanter Surface Length and Bi-trochanter Surface Length; 53 and 63 are standard deviations of the two measurements; and 3.1 is the Z value for covering 99.9 percent of male LEO population which will cover almost all females as well. To estimate the needed seat belt length, a 580-mm additional web length would be necessary based on common seat installations, which includes an adjustment of 300 mm for the left trochanter to belt anchor point, 60 mm for the right trochanter to buckle point for the lap-belt and shoulder-belt components, and 220 mm for acromion to shoulder belt anchor point (Hsiao et al., 2015). In summary, the required minimum length of pelvic and upper torso restraint would be 2496 mm: $(837 + 53 \times 3.1) + (719 + 63 \times 3.1) + 580 = 1001.3 + 914.3 + 580 = 2495.6$ mm. The minimum seat belt webbing length would need to be further extended when seat up/down and fore/aft adjustments are required. The new replacement adjustable lap and shoulder webbing (3-point retractable seat belt) currently seen in the market has a total length of 3378 mm and thus should fit the needs of LEO vehicles.

It should be noted that about 5% LEOs in our study used seat belt extenders and body weight is associated with the need for a seat belt extender. The LEO group who used a seat belt extender had a greater mean of body weight than their counterpart group. It is understandable that individuals may have unique anthropometric compositions. In addition, seat adjustment range or constraint can affect the useable length of seat belt. Seat belt extenders provide an alternative to accommodate individual needs.

4.6. Practical implications

The stratified national LEO study on challenges in patrol vehicles considered sex, age, and ethnicity/race factors in the study. The results revealed that 88% LEOs reported some discomfort/pain at the end of a shift with a major discomfort at the lower back and hip. Nine body dimensions (Stature, buttock-popliteal length, eye height - sitting, knee height - sitting, shoulder-grip length, popliteal height, sitting height, hip breadth, and body mass index) were associated with seat adjustment needs in fore/aft and up/down directions. In addition, another 12 variables had some correlation to seat fore/after adjustment needs. Moreover, body weight is associated with the use of a seatbelt extender. LEO vehicle and equipment manufacturers and designers can use the abovementioned 9 key parameters, along with body weight information, to build their initial prototypes for testing improved vehicle and equipment designs for inclusivity. Since the seat adjustment and equipment layout involve multiple LEO body dimensions, use of a multivariate approach or computerized digital LEO avatars to finalize the adjustment ranges for seat and equipment in the console space would be the choice. This study identified key dimensions for multivariate analyses. The needed representative LEO avatars (or real subjects) and their body dimensions based on this assessment study will be presented in a companion paper (Hsiao et al., 2022). The adjustment ranges for seat and equipment for LEO vehicles will then be drawn accordingly.

4.7. Study limitations

Any anthropometry and equipment usability survey naturally has certain potential limitations, such as sampling bias, measurement error, self-reporting bias, and missing data. To control sampling bias, the LEO sample in this study was specified based on the geographic density of racial/ethnic distributions from the 2010 U.S. Census by four census regions (U.S. Census Bureau, 2012) and the best available population age distribution in 2016 from the U.S. Census Bureau (2022). It is rare that a survey sample acquisition exactly matches a sampling plan, and a statistical weighting method is typically utilized to apply the ratio of the actual sample to the target sample for each individual acquired value to represent the population of interest (Hsiao et al., 2021). Our sample outcomes by racial/ethnic and age groups were very close to those of the original sampling plan. The unweighted and weighted data would be comparable in means. We elected to use unweighted data in this report for simplicity. Since it took ten years to complete the study (from the planning stage to various administrative and scientific reviews, to data collection), the racial/ethnic, age, and sex distributions may have changed to some extent during the 10 years, which is a limitation of the data.

Imprecision in anthropometry measurements can occur in both inter-measurers and intra-measurers. The data collection phase of this study across 12 U.S. States lasted for 24 months. Two teams of four anthropometry data collection specialists each were trained to conduct the data collection - two for traditional anthropometry measurements and two for 3-dimensional scans for each team. To assure consistency in data collection and measurement accuracy, the trained specialists practiced data collection procedures the day before the data collection period for each data collection site, using the allowable inter- and intra-measurer errors defined in a Measurer's Handbook (Hotzman et al., 2011) as the guide. With the special attention, we had only a dozen of unverifiable data at the data-quality check stage. We treated them as missing data.

Thirteen equipment-useability survey questions were employed in this study. Self-reported data is subject to various biases, such as selective memory, overestimation, and information overload, which can be difficult to verify. This study used an iPad for LEOs to answer questions or tick their responses. They were allowed sufficient time to address the questions so to minimize the potential bias associated with time constraint or information overload.

Missing data and low response rate are common challenges for questionnaire surveys. Question fatigue, loss of interest, and inexperience with a topic are among the causes of the challenges. This stratified sampling survey integrated the questionnaire survey in the in-person anthropometry measurement section with a 91.4% response rate (8.6% of missing data for a few questions) which is considered a very successful survey. We did not conduct a follow up analysis to fill in or interpret any missing data, which is a limitation.

5. Conclusion

The increasing trend of females in patrolling occupations from 5% in 1980 to 17.6% in 2019, distinct anthropometric differences between male and female LEOs, and longer career service among LEOs (i.e., a third of officers had served 16 years or more) point to the need to rethink current in-vehicle equipment layout, vehicle seat adjustment, and equipment design for the safety and well-being of LEOs. LEOs on average spent 59% of their time (5.4 h) in vehicles and 55% of them entered and exited vehicles 16 times or more during a typical shift. About 40.7% officers felt inadequate levels of seat adjustment; female officers needed more up/down adjustment while male officers needed more fore/aft adjustment. Eighty-eight percent (88%) of officers reported some discomfort/pain at the end of a shift, and the most affected body areas were the lower back and hip. Handguns, radios, and handcuffs on duty belts were the leading equipment associated with the seated discomfort/pain. In addition, about a third of officers experienced neck pain associated with the use of mobile data terminals mounted in the vehicle. Adjustments were needed in all directions. Stature, buttock-popliteal length, eye height (sitting), knee height (sitting), shoulder-grip length, popliteal height, sitting height, hip breadth, and body mass index are key parameters associated with seat adjustment needs. This information, along with the newly available LEO anthropometry data (Hsiao et al., 2021), provide a foundation for updating specifications and designs of LEO vehicle equipment and the LEO-equipment interface to achieve improvements in LEO safety and well-being.

Disclaimer

The findings and conclusions in this report are those of the author and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC) or Texas A&M University System. Mention of any company or product does not constitute endorsement by NIOSH, CDC, or Texas A&M University.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This research was initiated when Dr. Hongwei Hsiao was Chief of the Protective Technology Branch and Coordinator for the Center for Occupational Robotics Research at the National Institute for Occupational Safety and Health (NIOSH). He was the project officer and principal investigator. The research was funded through the NIOSH National Occupational Research Agenda. The author extends his gratefulness to the entire research team, collaborators, and many others who provided technical and administrative support to the NIOSH National Law Enforcement Officer (LEO) Anthropometry Research project. The results presented in this manuscript were part of the national NIOSH LEO anthropometry study. The project team members included Richard Whisler, Joyce Zwiener, Darlene Weaver, Mathew Hause, Bradley Newbraugh, Mahmood Ronaghi, James Green, Tony McKenzie, Gene Hill, Bruce Bradtmiller, Belva Rockwell, Vernon McDougall, and Tiffany Brake. The industrial partners and stakeholders included the National Sheriffs' Association (NSA), Fraternal Order of Police (FOP), International Association of Chiefs of Police (IACP), State University of New York at Buffalo, National Institute of Justice (NIJ), Federal Law Enforcement Training Centers (FLETC), Federal Law Enforcement Officers Association (FLEOA), U.S. Army Natick Soldier Research, Development, Engineering Center (NSRDEC), and National Institute of Standards and Technology (NIST). Special thanks go to the twelves police stations and training centers in Arizona, Colorado, Maryland, Massachusetts, Minnesota, North Carolina, Ohio, Oklahoma, Tennessee, Uta, Virginia, and Wisconsin who participated in the full study and the police station in West Virginia who contributed to a pilot study before this full study.

References

Arnold, J., 2000. Millennium backsaver duty belt suspender. Technical Memorandum. Canadian Police Research Centre. TM-01-2000. http://publications.gc.ca/collections/collection_2007/ps-sp/PS63-1-2000-1E.pdf.

Arts, G.A., 2006. Low back pain in police officers. Master's thesis. Grand Valley State University, Allendale, MI. https://scholarworks.gvsu.edu/cgi/viewcontent.cgi?article=1641&context=theses.

Brown, J.J., Wells, G.A., Trottier, A.J., Bonneau, J., Ferris, B., 1998. Back pain in a large Canadian police force. Spine 23 (7), 821–827. https://doi.org/10.1097/00007632-199804010-00017.

Burton, K.A., Tillotson, K.M., Symonds, T.L., Burke, C., Mathewson, T., 1996. Occupational risk factors for the first onset and subsequent course of low back trouble: a study of serving police officers. Spine 21 (22), 2612–2620. https://journals.lww.com/spinejournal/Fulltext/1996/11150/Occupational_Risk_Factors_for_the_First_Onset_and.11.aspx.

Chavez, N., 2017. How are police cars modified? CNN. https://www.cnn.com/2017/08/03/us/qa-modified-police-cars/index.html.

Cordner, G., Cordner, A., 2011. Stuck on a plateau? Obstacles to recruitment, selection, and retention of women police. Police Q. 14 (3), 207–226. https://doi:10.1177/1098611111413990.

Czarnecki, F., Janowitz, I., 2003. Ergonomics and safety in law enforcement. Clin. Occup. Environ. Med. 3, 399–417.

Donnelly, C.J., Callaghan, J.P., Durkin, J.L., 2009. The effect of an active lumbar system on the seating comfort of officers in police fleet vehicles. Int. J. Occup. Saf. Ergon. 15, 295–307. https://doi.org/10.1080/10803548.2009.11076809.

Filtness, A.J., Mitsopoulos-Rubens, E., Rudin-Brown, C.M., 2014. Police officer in-vehicle discomfort: appointments carriage method and vehicle seat features. Appl. Ergon. 45 (4), 1247–1256. https://doi.org/10.1016/j.apergo.2014.03.002.

Grabianowski, E., 2022. How police cars work. How Stuff Works. https://auto.howstuffworks.com/police-car1.htm. (Accessed 13 May 2022).

Gyi, D.E., Porter, J.M., 1998. Musculoskeletal problems and driving in police officers. Occup. Med. 48 (3), 153–160. https://doi.org/10.1093/occmed/48.3.153.

Hotzman, J., Gordon, C.C., Bradtmiller, B., Corner, B.D., Mucher, M., Kristensen, S., Paquette, S., Blackwell, C., 2011. Measurer's Handbook: US Army and Marine Corps Anthropometric Surveys, 2010-2011 (TR-11-017). U.S. Army Natick Soldier Research, Development, and Engineering Center, Natick, MA.

Hsiao, H., Kau, T.Y., Whisler, R., Zwiener, J., 2022. Body models of law enforcement officers for cruiser cab accommodation simulation. Hum. Factors (submitted for publication consideration).

Hsiao, H., Whisler, R., Weaver, D., Hause, M., Newbraugh, B., Zwiener, J., Ronaghi, M., Bradtmiller, B., Rockwell, B., McDougall, V., Brake, T., 2021. Encumbered and traditional anthropometry of law enforcement officers for vehicle workspace and protective equipment design. Hum. Factors. https://doi.org/10.1177/00187208211064371. Advance online publication.

Hsiao, H., Whitestone, J., Wilbur, M., Lackore, R., Routley, J.G., 2015. Seat and seatbelt accommodation in fire apparatus: anthropometric aspects. Appl. Ergon. 51, 137–151.

Kissiah, M., 2022. Police vehicles. EInvestigator.com. https://www.einvestigator.com/police-vehicles/. (Accessed 13 May 2022).

Larsen, L.B., Ramstrand, N., Tranberg, R., 2019. Duty belt or load-bearing vest? Discomfort and pressure distribution for police driving standard fleet vehicles. Appl. Ergon. 80, 146–151. https://doi.org/10.1016/j.apergo.2019.05.017.

McKinnon, C.D., Callaghan, J.P., Dickerson, C.R., 2011. Field quantification of physical exposures of police officers in vehicle operation. Int. J. Occup. Saf. Ergon. 17, 61–68. https://www.tandfonline.com/doi/pdf/10.1080/10803548.2011.11076870.

McKinnon, C.D., Amy, S.A., Callaghan, J.P., Dickerson, C.R., 2014. The effect of police cruiser restraint cage configuration on shoulder discomfort, muscular demands, upper limb postures, and task performance during simulated police patrol. Appl. Ergon. 45 (6), 1414–1421.

Mitsopoulos-Rubens, E., Trotter, M.J., Rudin-Brown, C.M., 2009. The interaction between police vehicles and police equipment and its role in injuries to police officers. In: Report 3: Survey. Final Report Prepared for WorkCover NSW through the Police Association of NSW. 2 July.

National Center for Health Statistics, 2004. National health and nutrition examination survey. Available at: http://www.cdc.gov/nchs/about/maior/nhanes/frequencv/mpq.htm. (Accessed 18 October 2004).

NIOSH, 2020. Evaluation of low back pain and duty equipment wear configurations in police officers. In: Ramsey, J.G., Eisenberg, J. (Eds.), Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Health Hazard Evaluation Report. 2017-0049-3367. https://www.cdc.gov/niosh/hhe/reports/pdfs/2017-0049-3367.pdf.

Saginus, K., Marklin, R., 2013. The effects of mobile computer location in a vehicle cab on muscle activity and body posture of large and small drivers. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 57, pp. 902–906, 1.

Saginus, K.A., Marklin, R.W., Seeley, P., Simoneau, G.G., Freier, S., 2011. Biomechanical effects of mobile computer location in a vehicle cab. Hum. Factors 53 (5), 474–488.

Shmagel, A., Foley, R., Ibrahim, H., 2016. Epidemiology of chronic low back pain in US adults: data from the 2009–2010 National Health and Nutrition Examination Survey. Arthritis Care Res. 68 (11), 1688–1694. https://doi.org/10.1002/acr.22890.

U.S. Bureau of Labor Statistics, 2020. Household Data Annual Averages 11. Employed Persons by Detailed Occupation, Sex, Race, and Hispanic or Latino Ethnicity, 2019.

U.S. Census Bureau, 2012. Employed Civilians by Occupation, Sex, Race, and Hispanic Origin: 2010. Labor Force, Employment, and Earnings. Page 394. Statistical Abstract of the United States, 2012.

U.S. Census Bureau, 2022. Historical Households Tables. Table HH-3. Households by age of householder: 1960 to present. https://www.census.gov/data/tables/time-series/demo/families/households.html. (Accessed 24 November 2022).
World Health Organization (WHO), 2022. Body Mass Index -BMI. https://www.euro.who.int/en/health-topics/disease-prevention/nutrition/a-healthy-lifestyle/body-mass-index-bmi?source=post_page——————————————————. (Accessed 19 May 2022).
Zahabi, M., Kaber, D., 2018. Identification of task demands and usability issues in police use of mobile computing terminals. Appl. Ergon. 66, 161–171.
Zahabi, M., Pankok Jr., C., Park, J., 2020. Human factors in police mobile computer terminals: a systematic review and survey of recent literature, guideline formulation, and future research directions. Appl. Ergon. 84, 103041 https://doi.org/10.1016/j.apergo.2019.103041.