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Duty belt or load-bearing vest? Discomfort and pressure distribution for police driving standard fleet vehicles.

1. Introduction

Police experience discomfort from wearing mandatory equipment while at work (Donnelly, Callaghan, & Durkin, 2009; Gruevski, Holmes, Gooyers, Dickerson, & Callaghan, 2016; Holmes, McKinnon, Dickerson, & Callaghan, 2013; Ramstrand & Larsen, 2012; Ramstrand, Zugner, Larsen, & Tranberg, 2016). The work situation for many police officers requires that they sit in fleet vehicles for long periods of time (Larsen, Andersson, Tranberg, & Ramstrand, 2018; McKinnon, Callaghan, & Dickerson, 2011) and this has previously been associated with musculoskeletal problems in the lower back (D. E. Gyi & Porter, 1998). In Sweden, the interior of police vehicles is not modified to accommodate for duty belts and body armour, which uniformed police are required to wear at all times.

Comfort and discomfort are constructs used in ergonomics to assess chair and vehicle seat design as well as sitting positions (Kyung, Nussbaum, & Babski-Reeves, 2008; Shackel, Chidsey, & Shipley, 1969; Zhang, Helander, & Drury, 1996). Zhang et al. (1996) suggest that comfort and discomfort are associated with different factors and indicate that the two constructs should be treated as different entities. They suggest that comfort is associated with the feeling of relaxation, wellbeing and aesthetic design whereas discomfort is associated with feelings of soreness, numbness, stiffness and pain. Discomfort is typically imposed by biomechanical factors such as posture, pressure distribution and muscle contraction (Helander & Zhang, 1997; Zhang et al., 1996). It has been hypothesised that discomfort could be reduced by eliminating the physical constraints introduced by biomechanical factors.

Studies investigating sitting discomfort in vehicles advocate the use of both subjective and objective measures (De Looze, Kuijt-Evers, & Van Dieën, 2003; Le, Rose, Knapik, & Marras, 2014). Subjective measures used to study discomfort associated with sitting in vehicles are typically standardised self-report measures such as the Automobile Seating Discomfort Questionnaire (Smith, Andrews, & Wawrow, 2006) and measures of discomfort in specific body regions (Mergl, Klendauer, Mangen, & Bubb, 2005).

Objective measures include pressure distribution, EMG analysis and kinematic measures of posture (De Looze et al., 2003; Le et al., 2014). Of these, pressure measurement appears to be the variable with the clearest association to subjective measures of discomfort (De Looze et al., 2003).

Discomfort related to the equipment worn by police has been addressed in numerous studies, both while walking and sitting (Donnelly et al., 2009; Filtness, Mitsopoulos-Rubens, & Rudin-Brown, 2014; Gruevski et al., 2016; Holmes et al., 2013; Ramstrand et al., 2016). Studies investigating ergonomic interventions to reduce discomfort while sitting in police fleet vehicles tend to address the issue by altering the design of either vehicle seat or load carriage system (Filtness et al., 2014; Holmes et al., 2013). Those focusing on seat design have indicated that lumbar or thoracic support-systems integrated into the backrest of seats have the potential to reduce self-reported discomfort and reduce pressure applied to the lower back during prolonged driving (Donnelly et al., 2009; Gruevski et al., 2016; Holmes et al., 2013). Those focusing on load carriage design have demonstrated that a reduced duty belt, or use of a load-bearing vest, is associated with lower levels of self-reported discomfort (Filtness et al., 2014; Holmes et al., 2013). Also, lower levels of pressure between body and backrest have been demonstrated when sitting in fleet vehicles with a reduced duty belt. The majority of these studies have investigated sitting under simulated driving or while sitting in a stationary vehicle.

As a means of reducing discomfort associated with wearing mandatory equipment, much attention has been given to investigating the relative effects of various load carriage designs worn by police (Filtness et al., 2014; Larsen, Tranberg, & Ramstrand, 2016; Ramstrand et al., 2016). Several police authorities have introduced load-bearing vests as a means of relocating appointments away from the pelvis (Filtness et al., 2014). To date, little is known of the relative effects that load-bearing vests may have on discomfort experienced by police and no studies have investigated sitting pressure associated with this load carriage design.

The aim of this study was to explore the relative effects of different load carriage designs on perceived discomfort and body-seat interface pressures in police when driving. It was hypothesised that relocating appointments away from the pelvis would lead to reduced interface pressure and increased contact area in the lower back.

2. Methods and Materials

2.1 Study design

A repeated measures study design was utilised with three conditions investigated; standard load carriage, alternate load carriage including a load-bearing vest and a control condition in which no equipment was worn. Each participant performed all three tests consecutively on the same day, either in the morning or afternoon. All testing was conducted in a standard Swedish police vehicle. This model of vehicle is classified as a station wagon with standard seats and is used widely by the Swedish police. The study was approved by the Regional Ethics Committee in Linköping, Sweden (dnr 2010/261-31).

2.2 Participants

Twenty-two subjects (eleven male and eleven female) were recruited from a medium-sized municipality in Sweden. All participants were police officers working in active duty. None of the participants had any self-reported musculoskeletal pain or injuries at the time of data collection. In their everyday load carriage system, eleven of the participants wore their weapon in a belt mounted hip holster while eleven wore it in a thigh holster attached to their duty belt. The placement of weapon corresponds to the side of the dominant hand and twenty-one of the participants wore their holster on the right side. Descriptive data related to the participants can be found in Table 1.

2.3 Load carriage design/system

Swedish police are required to wear both body armour and duty belt as a mandatory part of their uniform. The extra load added as a result of this mandated equipment is typically between 6-7 kg (Ramstrand et al., 2016). The standard load carriage system mandated by

the Swedish police authority includes a duty belt. Appointments that are required to be carried in the duty belt include; radio, OC spray, extra ammunition, handcuffs, torch and baton. The specific placement of weapons can vary depending upon the region and function within the police force. In order to standardise weapon placement in the standard load carriage condition, all participants were required to carrying their weapon in a belt mounted hip holster. All mandated appointments were required to be carried in the duty belt and standard issue body armour was also worn. The alternate load carriage condition comprised of a load-bearing vest which was worn on top of the body armour. The load-bearing vest used was a prototype specially developed for studying police load carriage. The vest had integrated pockets where OC spray, extra ammunition, handcuffs and torch were placed. The radio was attached to a strap at the height of on the chest. The weapon and baton were worn in a thigh holster fastened to a duty belt without any additional appointments. All participants wore their own standard issue body armour and appointments. If any additional appointments were worn in the duty belt at the time of data collection the participants were asked to remove these.

2.4 Instrumentation

2.4.1 Questionnaires

The Automobile Seating Discomfort Questionnaire (ASDQ) was used to assess discomfort related to the vehicle seat (Smith et al., 2006). Questions developed by Donnelly et al. (2009) relating to police specific tasks and equipment were also included. Ratings of perceived discomfort in 20 specific body regions were assessed using a questionnaire previously validated by Mergl et al. (2005). Both questionnaires have previously been used in studies investigating in-vehicle discomfort in police (Donnelly et al., 2009; Filtness et al., 2014; Holmes et al., 2013). All ratings of discomfort were assessed on a 100 mm visual analogue scale, with 0 mm representing no discomfort and 100 mm representing extreme discomfort. Both questionnaires were translated to Swedish, back-translated into English and tested on target group to ensure linguistic validity (WHO, 2010).

2.4.2 Pressure mapping.

Pressure data were collected using two mats designed for measuring sitting pressure (CONFORMat™ Tekscan, Inc. South Boston, USA). The pressure mats have a flexible structure with sensor cells embedded in a mesh which is covered with fabric and designed to accommodate to the shape of the surface being measured. Although participants in this study wore clothes and policing equipment during pressure measurements, in the context of this study we use the term participant/body-seat interface to describe the location of the pressure measurements. One mat was placed on the seat pan and the other against the backrest of the driver side of the vehicle. Participant-seat interface pressure was continuously measured at a frequency of 10 Hz during the whole driving session. Each mat measured 47.1×47.1 cm and included 1024 sensor cells distributed in a matrix of 32 rows and 32 columns. Each individual sensor cell covered an area of 2.14 cm^2 . Before data collection, equilibration of the two mats was performed in accordance with the manufactures instructions. The mats were attached to the seat pan and back rest using tape and were not removed between measurement sessions for each individual. To ensure the mats did not move when participants entered and exited the vehicle, the researchers assisted them by holding the mats and ensuring that they did not bend or buckle.

2.5 Experimental procedure

For each of the three conditions, participants drove a standardised route of 22 km. The route was chosen as it included varying speed limits, high-way driving and city driving. All tests were carried out during weekdays and due to traffic and the time of day for data collection, time to complete the route varied between 25 and 30 minutes. Before each driving session participants were instructed to make personal adjustments to the steering wheel and/or seat of the vehicle. No adjustments were allowed after the test procedure started or between the different conditions. Ratings of discomfort measures were collected at the end of each session while participants remained seated in the vehicle (Donnelly et al., 2009; Mergl et al., 2005; Smith et al., 2006). The order of all testing conditions was randomised.

2.6 Data analysis

Discomfort ratings from the two load carriage conditions were normalised by subtracting discomfort scores from the control condition (Gruevski et al., 2016; Holmes et al., 2013). A Wilcoxon signed-rank test was used to determine if there was a difference in median values between the standard and alternate load carriage conditions for ratings ≥ 10 mm.

Data from each pressure mapping trial was processed using COMFORMat Research software. For analysis purposes, the back rest was divided into two regions representing the upper back (16 rows and 32 columns) and lower back (15 rows and 32 columns). The seat pan was divided into four regions representing the left buttocks, right buttocks (15 rows and 16 columns), left thigh and right thigh (16 rows and 16 columns). The last row of each pressure mat, located at the junction of the seat pan and back rest, were excluded due to artefacts caused by sensor cells being bent. These pressure points were not included in any of the analysis. In figure 1, an example of pressure mapping of the two load carriage conditions and the control condition for one individual is presented to visually illustrate the data. Averages of contact pressure and contact area throughout the full driving period were calculated for each of the regions defined on the seat pan and backrest mats. As the main objective of this study was to explore the effects of load carriage design, a Wilcoxon signed rank test was used to determine if there was a difference in median values of contact pressure and contact area between the standard and alternate load carriage conditions. All statistical analyses were carried out using IBM SPSS Statistics 21 (IBM Corp, Armonk, NY, USA).

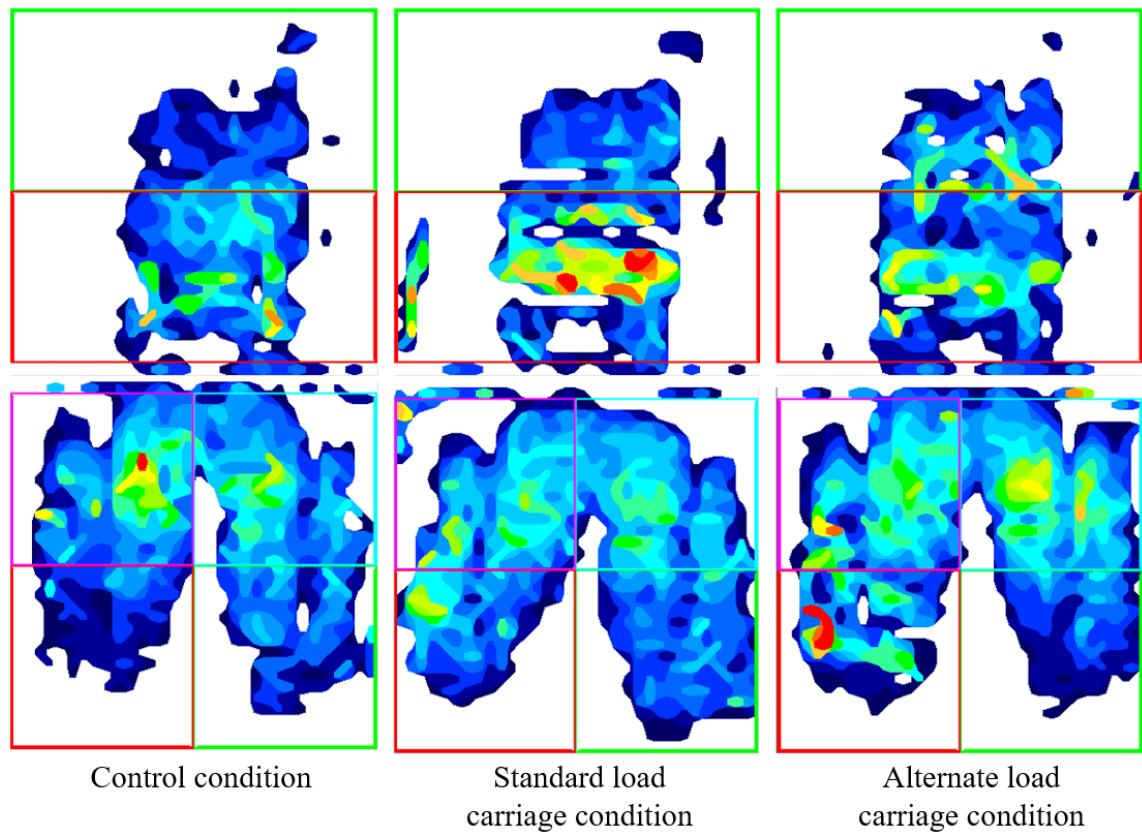


Figure 1. Pictures in the top row illustrate the back rest for the three conditions while bottom row pictures represent the seat pan. These pictures represent an average of all frames for one single participant. Red colours represent areas with high pressure and blue colours represent areas with low pressure. Contact pressure in the red coloured areas equals 185 mmHg or higher.

3. Results

3.1 Participants

All participants ($n = 22$) completed each of the three test conditions. Average age of participants in this study was 34.5 years ($SD = 10.8$; range 24 – 61), weight, 88.2 kg ($SD = 14.1$; range 61 – 119), height 1.77 m ($SD = 14.1$; range 1.64 – 1.86). The average number of years working as a police officer was 8 ($SD = 10.8$; range 0.5 – 37.5). Participant characteristics for female and male participants are presented separately in table 1.

Table 1

Participant characteristics

	Female				Male			
	Age (years)	Weight ^a (kg)	Height (m)	Years service	Age (years)	Weight ^a (kg)	Height (m)	Years service
	24	75	1.70	1	36	87.4	1.82	6
	41	89	1.69	5	31	98.9	1.85	6.5
	27	61	1.71	1	56	100	1.80	35
	29	92.4	1.68	4	60	105	1.83	37.5
	27	93.5	1.79	3.5	29	90.8	1.85	4
	30	119	1.75	4.5	28	102.8	1.86	3
	35	76	1.70	4	24	97	1.86	1
	27	83.5	1.72	4	61	74.5	1.86	31
	41	70.2	1.69	10	32	95	1.82	9
	28	67.4	1.83	1	36	95	1.73	4
	26	69.6	1.72	0.4	30	96.4	1.86	4
Mean	30.5	81.5	1.72	3.5	38.5	94.8	1.83	12.8
SD	5.6	15.6	0.3	2.6	13.6	8.0	0.4	14.0

^a Weight without mandatory equipment

3.2 Discomfort

Discomfort ratings for both the ASDQ and specific body regions were relatively low for both load carriage conditions. Few items exceeded scores greater than 10mm on the scale after scores from the control condition were subtracted. A total of 7 items scored discomfort ratings greater than 10 mm and these were only found for the standard load carriage condition (figure 2). Ratings in the standard load carriage condition were found to be significantly greater in 6 of the 7 items that recorded scores over 10mm. The greatest level of discomfort recorded on the ASDQ was caused by the duty belt in the standard load carriage condition (36mm; IQR 14 – 52 mm), this was followed by overall discomfort experienced when sitting in the seat (19.5mm; IQR 7 – 44) and discomfort caused by body armour (17.5mm; IQR 3 – 38mm). Body regions reported to have the greatest level of discomfort were the lower back in the standard load carriage condition (30.5mm; IQR 11 – 42mm), right and left pelvis (right 14.5mm; IQR 0 – 34mm; left 12mm; IQR 1 – 32mm) in the same condition.

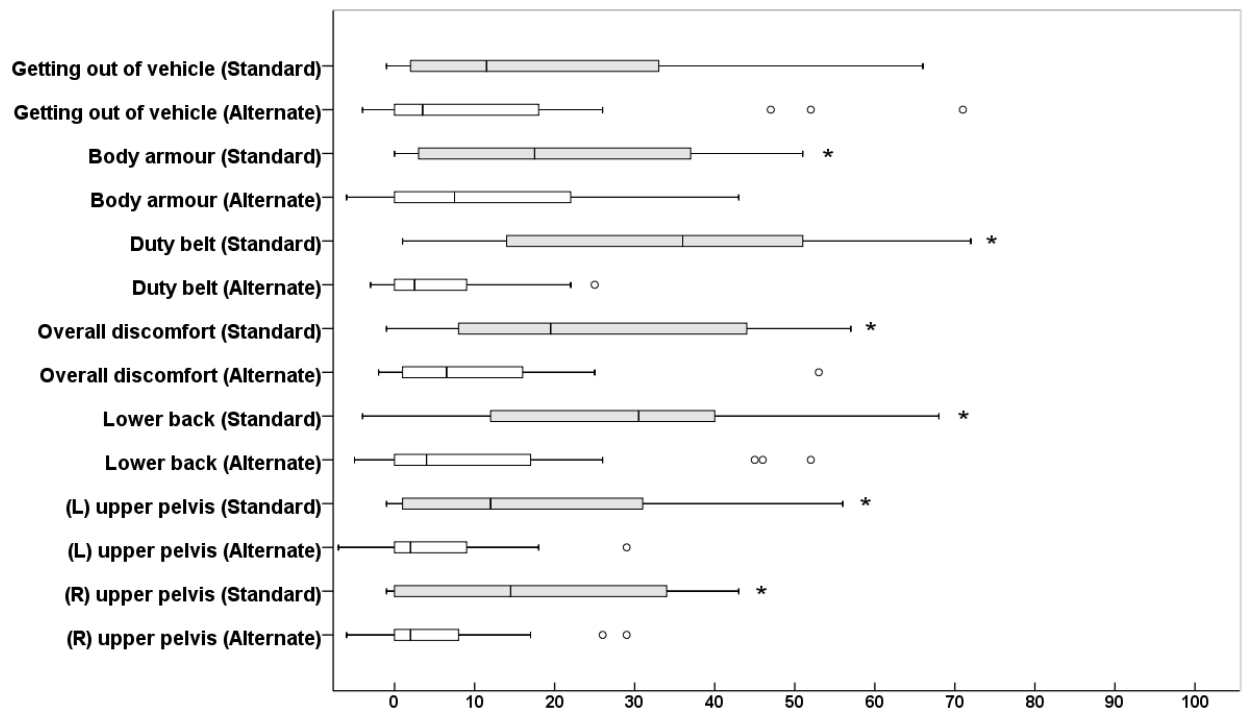


Figure 2. Discomfort ratings ≥ 10 mm. Values are in millimetres on a 100 mm scale with 100 mm representing high discomfort.

* denotes statistical significance at the level of $P < 0.05$ and \circ represents outliers

3.3 Pressure

Table 2 presents results of pressure measurements, averaged over the full driving period for each test condition. Contact pressures were lowest in each region when participants were driving under the control condition. Significant differences between the standard and alternate load carriage condition were observed in relation to both contact pressures and contact area ($p < 0.05$). In the alternate load carriage condition contact pressure was greater for the right thigh and upper back regions and lower for the lower back region when compared to the standard load carriage condition ($p < 0.05$). Contact area was lower for the right thigh and lower for the upper back in the alternate load carriage condition compared to the standard load carriage condition ($p < 0.05$).

Table 2.

Median contact pressure and area across load carriage conditions (interquartile range).
P-value reflects results from Wilcoxon signed rank test between the standard load carriage condition and the alternate load carriage condition.

	Control		Standard load carriage		Alternate load carriage		<i>p</i>
<i>Contact pressure (mmHg)</i>							
L buttocks	37.0	(31.6 - 42.1)	40.8	(36.7 - 43.9)	37.4	(34.2 - 44.6)	0.052
L thigh	22.8	(19.4 - 26.6)	26.0	(20.1 - 33.7)	26.0	(20.0 - 30.7)	0.332
R buttocks	39.8	(37.4 - 48.7)	41.3	(37.8 - 47.8)	40.6	(36.7 - 48.3)	0.709
R thigh	24.0	(20.6 - 31.6)	29.6	(23.8 - 37.0)	33.5 ^a	(28.3 - 38.0)	0.011
Lower back	25.3	(19.5 - 29.4)	37.8	(31.7 - 53.6)	35.2 ^a	(25.8 - 39.0)	0.010
Upper back	22.4	(18.8 - 23.5)	26.8	(21.7 - 29.8)	32.8 ^a	(25.9 - 36.5)	0.003
<i>Contact area (cm²)</i>							
L buttocks	391.7	(372.7 - 425.3)	393.4	(373.1 - 428.4)	424.7	(390.7 - 447.5)	0.100
L thigh	247.1	(213.7 - 294.8)	281.6	(227.0 - 337.0)	248.6 ^a	(198.4 - 312.6)	0.033
R buttocks	407.8	(359.8 - 445.5)	384.5	(367.6 - 434.1)	405.7	(365.1 - 439.2)	0.351
R thigh	317.6	(263.4 - 348.9)	297.5	(253.8 - 362.9)	285.4	(244.6 - 338.0)	0.126
Lower back	371.8	(314.4 - 436.2)	342.9	(272.9 - 404.9)	362.8	(299.8 - 404.3)	0.948
Upper back	346.1	(289.8 - 427.5)	319.2	(233.5 - 399.8)	283.2 ^a	(259.2 - 332.0)	0.007

^a Significantly different from standard load carriage

Alpha level $P < 0.05$

4. Discussion

This study aimed to explore the relative effects of different load carriage designs on perceived discomfort and body-seat interface pressures in police when driving. Results related to perceived discomfort revealed a clear preference for the alternate load carriage condition, where appointments from the duty belt were relocated to a load-bearing vest and a thigh holster. Differences in relation to pressure between the two load carriage conditions were mainly found for variables related to the back. The load-bearing vest condition resulted in reduced pressures recorded in the region of the lower back however pressures increased in the region of the upper back. The long-term consequence of this needs to be determined before recommendations can be made supporting one load-carriage condition over another.

Perceived discomfort was significantly greater when wearing the fully equipped standard duty belt compared to the alternate load carriage condition. Previous studies have found

similar results when investigating the effects of reducing or relocating appointments carried in the duty belt (Filtness et al., 2014; Holmes et al., 2013). These studies have focused on discomfort in the lumbar region when appointments were removed or relocated from the posterior part of the duty belt. To date there has been little discussion regarding the effects that anterior and laterally placed appointments have on sitting postures and discomfort. It is likely that these appointments would restrict hip flexion during sitting and may have consequences for discomfort experienced in the lumbar region. In the present study this issue was addressed by removing the belt entirely and utilising a thigh holster and load-bearing vest.

In this study self-reported discomfort experienced by participants, as well as continuous measurement of interface pressures were variables chosen as outcomes to evaluate the effect of different load carriage systems used by police. These variables served to provide both a subjective and objective perspective of load carriage systems while driving. The pressure experienced by the body as a result of wearing equipment and duty belts is considered a major source of discomfort for many police officers, especially while driving police vehicles (Larsen et al., 2018). For this reason, measures of relative pressure with different load carriage configurations was of particular interest in this study. While interface pressure provides useful information related to load distribution, it is not strongly correlated with subjective reports of discomfort (Diane E. Gyi & Porter, 1999; Kyung & Nussbaum, 2008). As such, objective measures of pressure and subjective ratings of discomfort were handled separately in our analysis.

The body regions in which greatest discomfort was recorded were the lower back and upper pelvic area, corresponding to the position of the duty belt. Numerous studies report the lower back to be the body region with greatest levels of discomfort in police while driving (Donnelly et al., 2009; Filtness et al., 2014; Gruevski, McKinnon, Dickerson, & Callaghan, 2013; D. E. Gyi & Porter, 1998; Diane E. Gyi & Porter, 1999) and in both simulated and field tests conducted with police, discomfort in the lower back has been found to increase with prolonged driving (Donnelly et al., 2009; Gruevski et al., 2016; Holmes et al., 2013). Both Holmes et al. (2013) and Gruevski et al. (2016) found an increase in lower back discomfort after each 15-minute interval of simulated driving over a time span of 120 minutes. In the present study, the duration of the driving sessions

varied between 25 and 30 minutes which is considered adequate exposure to detect a difference in discomfort between conditions.

Discomfort reported in the lower back which is greater than 20 mm in a static working posture, has been suggested to predict future musculoskeletal pain (Hamberg-van Reenen et al., 2008). In the present study the median value of lower back discomfort in the standard load carriage condition was 30.5 mm. Considering the limited possibility for police to change sitting posture in fleet vehicles, this particular working posture could be seen as somewhat static (Holmes et al., 2013). The combination of lower back discomfort, static working posture and prolonged driving (Larsen et al., 2018; McKinnon et al., 2011) may subsequently be a contributing factor to the high prevalence of lower back pain reported among Swedish police.

Carrying police equipment in a standard duty belt is not a desirable ergonomic situation when sitting for long periods of time in a police vehicle. Both duty belt and safety vest can influence pressure experienced at the interface between the body and car seat and this is a working situation where many police officers experience discomfort (Larsen et al., 2018) When investigating contact pressure at the interface between the body and seat, differences between the two load-carriage conditions were found for the right thigh, lower back and upper back. In the alternate load carriage condition, right thigh pressures were found to be higher when compared to the standard load carriage condition. This difference could be attributed to the relocation of weapon from the hip to the thigh, which was worn on the right-hand side for all participants except one. In this instance it is likely that the increased pressure was a result of the weapon in the thigh holster contacting the pressure mat rather than pressure from the thigh itself.

Contact pressures measured against the back rest showed a decrease in lower back pressure and an increase in upper back pressure when wearing the load-bearing vest compared to the standard load carriage condition. The decrease in lower back pressure partly confirms the hypothesis related to the effect of removing appointments and duty belt but an increase in contact area was expected and not found. The increase in upper back pressure when wearing the load-bearing vest was accompanied by a reduced contact area. According to the force/pressure relationship, a reduced contact area would be expected to result in an increase in pressure, however in this instance it is important to recognise that it is not simply contact area that is changing but also the force applied by

the upper back, which is greater in the load-bearing vest condition. This increased force application would also serve to increase pressure. Differences observed between load carriage conditions subsequently indicate that sitting postures are affected by different load carriage conditions. It could be hypothesised that the alternate load carriage condition permits the buttocks and lower back to be positioned more posterior on the seat and, as a consequence, the upper body would apply more force to the backrest. This does not however explain the reduced contact area observed in the upper back region when wearing the alternate load-carriage condition. To further understand this situation, hip flexion angles would need to be recorded. Previous studies using pressure mapping techniques to investigate the sitting situation in police fleet vehicles have focused only on modifications of the vehicle seat to accommodate for equipment worn by police (Gruevski et al., 2016; Holmes et al., 2013). As no previous studies have investigated the effects of different load carriage systems while driving police fleet vehicle comparisons to other studies are not possible.

A potential limitation in the present study was the restricted time for participants to accommodate to each load carriage condition. This was mainly an issue for those participants who were not familiar with carrying the weapon in a thigh holster. Another limitation was that it was not possible to blind participants to the load carriage system they were wearing. Expectations of police regarding the alternate load carriage condition may have introduced some bias in the discomfort ratings. The range of experience as police was very wide in this study and it is also possible that individuals who had been working for a longer period of time would experience greater discomfort.

Data was analysed by dividing the pressure mat into predefined regions and results may have been affected by participants of different sizes or with different sitting positions. In future studies one could consider marking anatomical landmarks on the pressure mat and using these to define regions of interest.

A great strength in this study was that both fleet vehicle and the route for each driving session mirrored the actual work situation of police working in active duty. The results of this research should generate discussion about current ergonomic issues related to equipment carriage and sitting in police vehicles. With such a high number of police reporting musculoskeletal pain, especially in the lower back region, more flexibility in carriage design and distribution of equipment on the body should be explored and

evaluated. Relocating equipment carried around the waist could be one solution, but any alternate load carriage situations should be carefully evaluated to avoid moving the problem to another body region. Reducing time sitting in police vehicles is another factor which could potentially benefit the work ergonomics of police. This is however closely related to planning of police work and should therefore be discussed on an organisational level.

Discomfort ratings greater than 10 mm after subtracting the control condition were set as the limit for being relevant to include in the statistical analysis. This is a relatively low discomfort score and previous studies including police have set the limit for including specific variables at 20 mm or 30 mm (Donnelly et al., 2009; Filtner et al., 2014). Previous studies have suggested that a change in pain intensity score of 10 mm or more on a 100 mm scale is relevant for outcomes related to musculoskeletal pain (Dworkin et al., 2009). For variables included in the analysis of this study, the difference between discomfort scores for load carriage conditions was greater than 10 mm for all variables except the variable “discomfort from getting out of the vehicle”.

5. Conclusion

Use of a load-bearing vest and thigh holster have been demonstrated to decrease discomfort and body-seat interface pressures in the lower back region in police driving fleet vehicles. The use of this alternate load carriage system should be further investigated as a possible ergonomic intervention to decrease musculoskeletal pain experienced by Swedish police working in active duty.

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