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Light armoured vehicle (LAV) occupant seated postures

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IMPORTANT INFORMATIVE STATEMENTS

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The data collected as part of this study was approved either by Defence Research and Development Canada's Human Research Ethics Board or by the Director General Military Personnel Research & Analysis' Social Science Research Review Board.

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Abstract

Military vehicles have the distinction of transporting fully kitted soldiers. The seated postures, and the influence of personal protective equipment (PPE) to soldier seated postures in light armoured vehicles (LAV) were not well understood. This study looked at the seated posture changes that occur when soldiers were wearing their PPE in three different LAV (LAV III, LAV 6 and LAV LORIT) while seated in three seats (passenger, driver and turret). A total of 23 male participants were monitored with inertial accelerometers to determine body posture angles while seated in LAV seats. Seated posture changes were evaluated with different levels of PPE, while seated in the three seats within the three LAV. Statistically significant differences were found between interactions involving PPE and vehicle seats. Participant seated postures were characterized showing differences between the different LAV seat designs. Footrest use effects on participant seated postures were evaluated with a participant subgroup ($n = 12$). Participant seated postures with footrest use resulted in lumbar kyphosis. The unsupported spinal curvature of another 30 participants were evaluated with a Valedo® Shape spinal mouse. Footrest use was re-evaluated with this tool, and showed a significant increase in lumbar kyphosis, and an increase in pelvic tilt extension.

Résumé

Les véhicules militaires ont la particularité de transporter des soldats en tenue complète. Les postures assises et l'influence de l'équipement de protection individuelle (EPI) sur la posture assise des soldats dans un véhicule blindé léger (VBL) n'étaient pas bien comprises. La présente étude visait à examiner les changements observés dans la posture assise chez les soldats qui portent leur EPI dans trois différents VBL (VBL III, VBL 6 et VBL LORIT) selon leur position dans le véhicule (c'est-à-dire le siège du passager, le siège du conducteur et le siège de la tourelle). Au total, 23 participants de sexe masculin ont été suivis au moyen d'accéléromètres inertiels afin de déterminer les angles d'inclinaison de leur posture alors qu'ils étaient assis dans le VBL. Les changements observés dans la posture assise ont été évalués en fonction du port de différents niveaux d'EPI, et ce, pour chacun des trois sièges dans le VBL. Des différences statistiquement significatives ont été constatées quant aux interactions entre l'EPI et le siège occupé dans le véhicule. Les postures assises des participants ont été caractérisées selon les différences relatives à la conception des sièges de VBL. L'effet de l'utilisation d'un repose-pieds sur la posture assise des participants a été évalué auprès d'un sous-groupe de participants (n = 12). Chez les participants utilisant un repose-pieds, la posture assise a provoqué une cyphose lombaire. La courbure de la colonne vertébrale de 30 autres participants en position sans appui a été évaluée au moyen d'un dispositif Valedo^MD Shape Spinal Mouse. L'utilisation d'un repose-pieds a été réévaluée à l'aide de cet outil, ce qui a révélé une augmentation significative de la cyphose lombaire et une augmentation de l'inclinaison du bassin en extension.

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Acknowledgements

We wish to acknowledge the DRDC Toronto Research Centre for loaning the Delsys® Trigno™ system for our study. Thank you to all the soldiers that participated in this study. All photos were taken by Capt Tommy Poirier, Cpl Olivier Hamel and Capt Gabrielle Chafé. A special thank you to co-author Adrienne Sy for her valued technical assistance.

1 Introduction

In the most recent combat operations conducted by the Canadian Armed Forces (CAF), mines and improvised explosive devices (IEDs) were a serious threat to ground vehicles and their occupants. When assessing vehicles, the recommended injury criteria and models were based mostly on automotive and aviation data. These may or may not be entirely applicable to the military context as the magnitude and force directions of the blasts are different. Concerns that there are gaps in the injury criteria, as well as in the methodology used for vehicle occupants' injury risk testing were raised within the international military community (NATO Research and Technology Organisation (RTO) Technical report HFM-090 Task Group 25, 2007).

Soldiers wear personnel protective equipment (PPE), they carry loads (e.g., ammunition, water, first aid supplies, etc.) that vary with their roles and missions, and there are various seat systems in the CAF light armoured vehicle (LAV) fleet (Figure 1). All of these aspects combined together can influence the seated posture of vehicle occupants. In order to correctly assess and realistically recreate scenarios with manikins in a laboratory setting, these seated postures need to be defined and characterised while encompassing the effects of the equipment worn by soldiers in ground vehicles. This study includes semi-clothed anthropometry of participants, participant seated posture angles in various seat systems and PPE dress conditions, as well as unsupported seated spine curvature measurements (i.e., no backrest). The LAV Operational Requirements Integration Task (LAV LORIT) passenger seat had a footrest; this study also looked at the effects of placing feet on the footrest on body posture angles and spine curvature.

Figure 1: *Light Armoured Vehicle 6.*

Vehicle occupant postures have been reported to be assessed using a sonic digitizer probe or a coordinate measurement device where participant joint coordinates were localized within a vehicle seat mock-up in a laboratory setting, and body segment angles were calculated to determine body posture (Reed et al., 1999). Mork and Westgaard (2009) looked at back posture alongside muscle activity in female computer workers.

They used inclinometers (electrolytic liquid sensors) to capture back posture angles in the sagittal plane, similar to accelerometers. A similar study was done with accelerometers to determine body posture angles in the sagittal plane referenced to the vertical axis, focussing on back postures and muscle activation, during seated office work activities (Mörl and Bradl, 2013). When working within the vehicles, it was decided to use wireless accelerometers to determine seated body postures in the sagittal plane. Body postures were defined by the relative angle of body segments as a function of accelerometer placement on the body in the sagittal plane as referenced by the true vertical or horizontal axes. In our study, we used the Delsys® Trigno™ Wireless System as an inertial accelerometer to measure participant body segment angles while seated in the LAV.

Previous research looking at spine curvature reported changes from the standing to the seated posture. These differences were observed with radiographic images (De Carvalho et al., 2010; Cho et al., 2015) and optical tracking systems (Claus et al., 2016).

To further define spinal curvature, a Valedo® Shape spinal mouse was used. The Valedo® Shape spinal mouse has previously been used for clinical and research purposes. Guermazi et al. (2006) looked at the validity and the reproducibility of the tool, showing good results for all spinal segments except for the L5-S1 measurements. Mannion et al. (2004) reported that global segments were more reliable than individual vertebral segment measurements, and considered the tool useful for clinical monitoring. Other researchers have used the Valedo® Shape spinal mouse to study spinal curvature flexibility in athletes (Muyor et al., 2011), and more specifically in response to hamstring extensibility (Lopez-Minarro et al., 2012a; Lopez-Minarro et al., 2012b).

The characterisation of vehicle seated occupants will enhance the development of instrumented spine surrogates for use in manikins, with the follow on of developing injury risk criteria that would increase soldier survivability against anti-vehicular landmine effects.

2 Methods

The study consisted of characterising the body segments in the sagittal plane in seated postures while wearing PPE and load carriage equipment, while seated within military light armoured vehicles. More specifically, a focus on spinal postures in the seated position, and a glimpse into the effects on seated spine curvature when raising the feet off the floor onto footrests.

2.1 Participants

Fifty eight male military members, aged 18 to 60, were recruited as participants for this study. No female participants were available at the time of the study. Participants had varying levels of familiarity with the vehicle seating systems depending on the position (e.g., driver, gunner, or passenger). Participant selection attempted to ensure semi-clothed anthropometric measurements of stature, sitting height, buttock to knee length (sitting), knee height (sitting) and weight encompassed the 5th to 95th percentiles of the male combat arms group of the 2012 Canadian Forces Anthropometric Survey (CFAS) (Keefe et al., 2015).

2.2 Anthropometry

2.2.1 Instruments

The following instruments were used to capture semi-clothed anthropometric measurements:

- GPM anthropometer, 0–2100 mm with base plate and sliding horizontal arm
- Lufkin steel measuring tape
- Heath-o-meter digital weight scale

2.2.2 Measurements

Participants were shirtless or wearing a t-shirt, they were wearing shorts or combat pants, as well as their boots during measurements. Each measurement was taken in duplicate, and the average reported. When duplicate measurements were outside the allowable observer error (AOE) (Hotzman et al., 2011), measurements were repeated till two measures were within the AOE. The following anthropometric measurements were taken for each participant as described in the 2012 CFAS (Keefe et al., 2015):

- Weight
- Stature
- Sitting height[1]
- Knee height, sitting
- Buttock to knee length, sitting

[1] For participants 1–28, seated height was taken while wearing a helmet. No correction was made to estimate thickness of helmet.

2.3 Seated posture angles

The Delsys® Trigno™ Wireless System combined electromyography and inertial accelerometers, were used to capture participant seated body posture in the sagittal plane within the LAV. Only the accelerometer function of the system was used during this study. The test matrix looked at 3 different vehicles, 3 different seats within those vehicles, and while wearing 3 different clothing conditions. The LAV evaluated were the LAV III, LAV 6 and LAV LORIT.

2.3.1 Vehicle seats

The test matrix evaluated three different seats within the LAV vehicles, Figures 2, 4 and 5 shows the passenger, driver, and turret seats, respectively, and their differences between the three vehicles.

The bench style seating of the LAV III and LAV 6 had a removable bench back (seen in Figure 2B), and the storage area behind the bench were partly empty (Figure 2A). The LAV LORIT passenger seat (Figure 2C) had a seat pan angle of 3°, and the backrest angle was 106°.

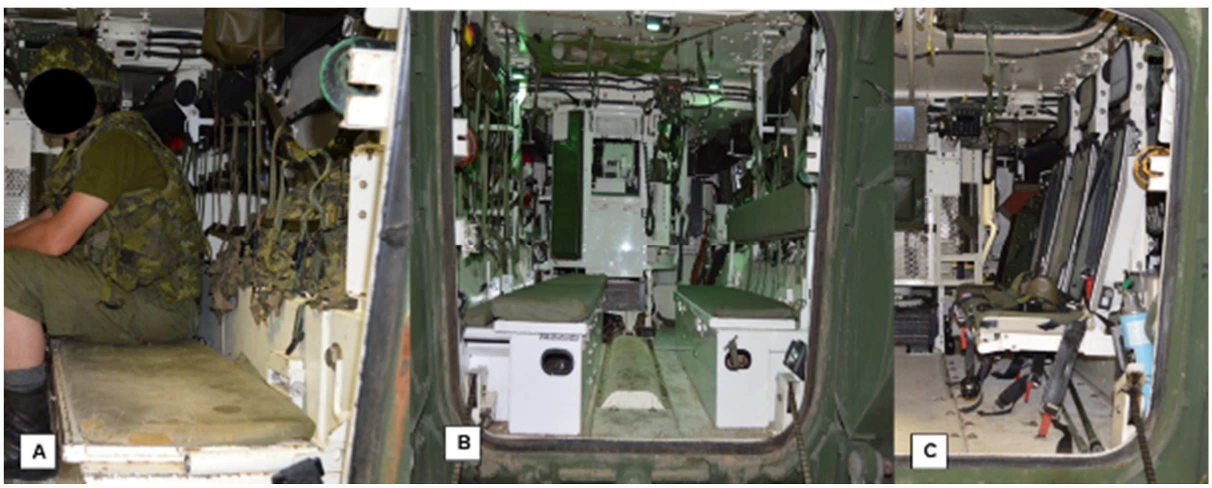

Figure 2: *LAV passenger seating A) LAV III, B) LAV 6 and C) LAV LORIT.*

Additionally, the LAV LORIT passenger seating had footrests. Participant seated posture angles were measured while wearing PPE with ballistic plates (PPEP) with feet on seat footrest (Figure 3A), and feet on footrest of the seat across (Figure 3B).

Figure 3*: Passenger seating in LAV LORIT with A) feet on seat footrest and B) feet on footrest of the seat across.*

The driver seats of the different vehicles were similar in that they were all adjustable, the backrest could be reclined completely to the floor to allow for emergency exit through the rear (e.g., in the LAV 6 the backrest could be set between 74° and 168°). The seat pan angle was adjustable (e.g., the LAV 6 driver seat pan could be set between 3° and 9°), the seat pan horizontal distance from the steering wheel was adjustable, and the vehicle pedals were also adjustable, both in horizontal distance and vertical height on an arc adjustment path. Visually, the padding of the three vehicles were different, the LAV III backrest and seat pan padding seemed thicker than the other two vehicles (Figure 4A), the LAV 6 also had thick padding (Figure 4B), while the LAV LORIT seat pan and backrest had a shaped thin padding (Figure 4C).

Figure 4: *LAV driver seating A) LAV III, B) LAV 6 and C) LAV LORIT.*

The turret seats were attached to a column type system enabling seat elevation for crew commanders and gunners to have their heads outside through the roof hatch as required by the mission. Accordingly, the turret seat backrest angles were 86° (LAV 6), and 97° (LAV LORIT), and seat pan angles were 6° and 0°, respectively. The turret seats had differences in their design, the LAV 6 turret seat pan had padding which extended over and around the front edge (Figure 5A) and the backrest was composed of 2 overlapping sections. The LAV LORIT seat pan padding was thicker in comparison, and did not carry over the edge, however, the seat pan frame dipped down at the front edge (Figure 5B). The backrest of the LAV LORIT had a shaped and thick padding (Figure 5B).

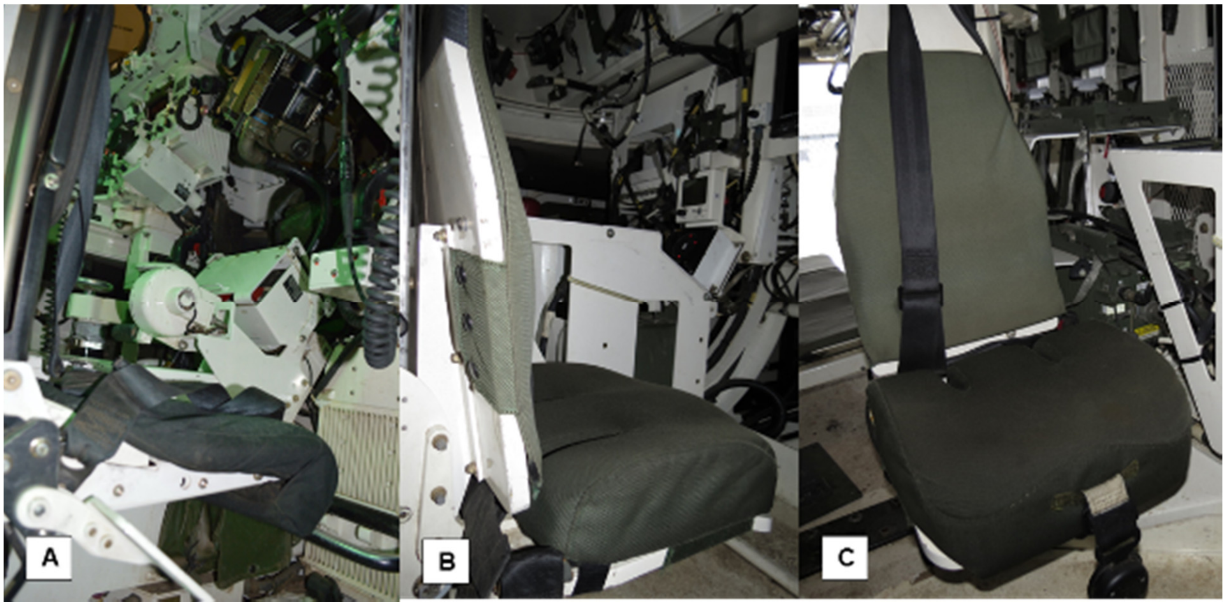

Figure 5: *LAV turret seat A) LAV 6, B) LAV LORIT side view and, C) LAV LORIT front view.*

2.3.2 Clothing conditions

Participant seated posture angles were evaluated in three clothing conditions in all three seats (i.e., driver, passenger and turret seats) found in the LAV fleet (i.e., LAV III, LAV 6 and LAV LORIT) (Table 1).

Table 1*: Clothing worn while measuring participant seated body postures in LAV seats.*

Condition	Description	
	Passenger seat	**Driver and turret seats**
1- Baseline	Combat trousers or shorts, t-shirt, and combat boots.	
2A- Personal protective equipment (PPE)	Condition 1 + in-service helmet (CG634), fragmentation protective vest (FPV), and tactical vest with standard combat load.[1]	Condition 1 + in-service helmet (CG634), and FPV. [no tactical vest]
2B- PPE with plates (PPEP)	Condition 2A + ballistic plates.	Condition 2A [no tactical vest] + ballistic plates.

[1]Standard combat load consisted of 4 loaded dummy magazines, 2 dummy fragment grenades, 2 dummy smoke grenades, water, personal role radio, and 2 field dressings.

Of note, the dress conditions were different for the passenger seat, which included a loaded tactical vest (Figure 6B), than in the driver and turret seats (no tactical vest) (Figure 6C).

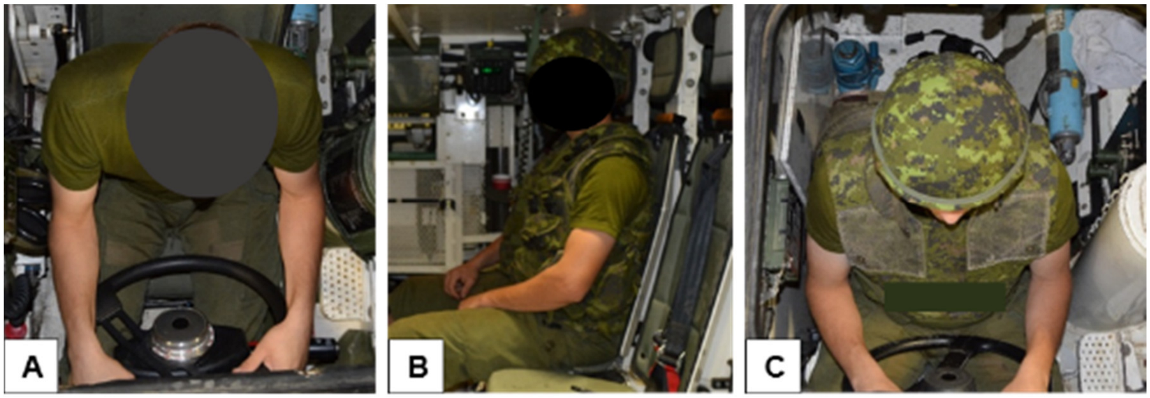

Figure 6: *Clothing conditions showing A) baseline, B) helmet, FPV and tactical vest in passenger seat, and C) helmet and FPV in turret and driver seats (no tactical vest).*

2.3.3 Accelerometer placement

The accelerometers were placed on the:

- Cervical 7th vertebra (C7) area to the right side (Figure 7A)
- Lumbar 5th vertebra (L5) area to the right side (Figure 7A)
- External side and middle of right thigh (Figure 7B)
- External side and middle of right calf (Figure 7B)
- Boot, attached to top and tip of boot (Figure 7B)

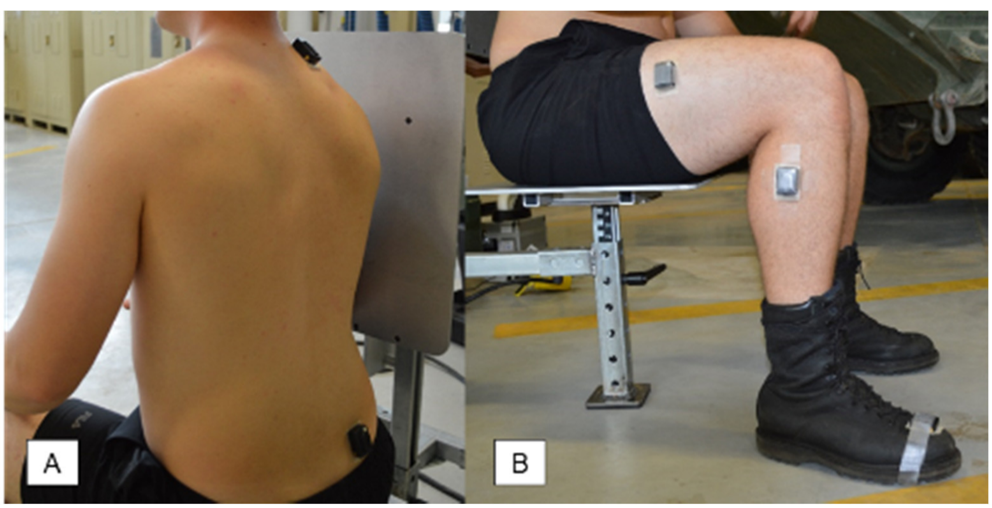

Figure 7: *Accelerometer placement in A) C7 vertebra area (top accelerometer) and L5 vertebra area (lower accelerometer), and B) right thigh, right mid-calf and top of right boot.*

The accelerometer readings were referenced with angle measurements collected while participants were sitting on an adjustable seat to achieve an isometric (ISO) 90 degrees seated posture (i.e., with feet flat, knees, thighs, and back at 90° angles relative to each other). These angles were relative to the sagittal plane, and confirmed with a digital inclinometer. Accelerometer readings were captured for 15–30 seconds at 150 Hz, the mean angle over the duration was calculated for each individual, and the participant group mean angles were reported with the standard deviation (stdev).

2.4 Seated spine curvature measurements

The Hocoma Valedo® Shape spinal mouse was used in this study to measure seated spine curvature in the sagittal plane. The spinal mouse consisted of two wheels that must be rolled along the spine, next to skin, from the C7 cervical vertebra all the way down to the S3 sacral vertebra (Figure 8). Participants were seated on a backless bench in a laboratory environment during these measurements.

Figure 8: *Spinal mouse measurement of participant in neutral seated posture.*

The spine curvature readings were conducted in triplicate measurements with 30 participants, by one examiner, in each seated posture to confirm consistency in the data capture. The individual triplicate averages were then grouped together, and the group mean and stdev (n = 30) were reported. Spine curvature was measured in three seated postures (Figure 9):

- ISO 90 posture (torso at 90°, knee at 90°)
- Seated lean forward
- Seated lean backward

Additionally, 2 raised legs postures (Figure 9D) were captured:

- Legs raised 20 degrees (footrest)
- Legs raised 40 degrees (footrest)

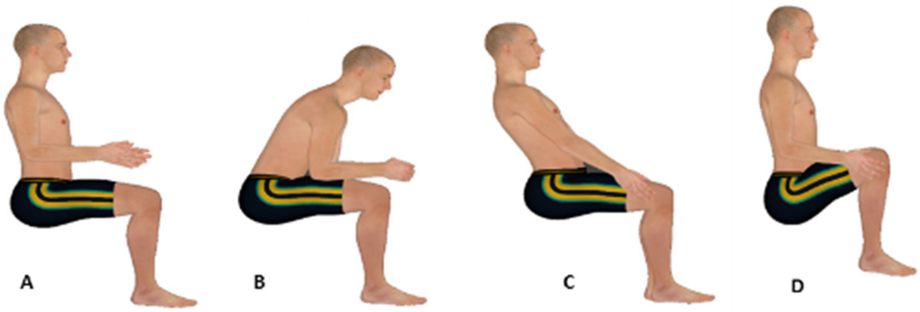

__Figure 9:__ Seated postures during spinal mouse measurements A) ISO 90 degrees, B) forward lean, C) backward lean and D) raised legs (footrest). Graphics design by Capt Tommy Poirier.

The spinal mouse software (Valedo Motion v2, Hocoma AG, Volketswil, Switzerland) generated segmental angles (between each vertebrae), regional angles (thoracic and lumbar regions), pelvic tilt (sagittal pelvic tilt angle in relation to vertical reference), vertical inclination (angle of direct connection line from S1 to C7 in relation to the vertical reference), and spine length in the sagittal plane. Segmental and regional angles were registered as either positive, indicating a kyphotic spine (spinous processes diverging), or negative indicating a lordotic spine (spinous processes converging) as shown in Figure 10.

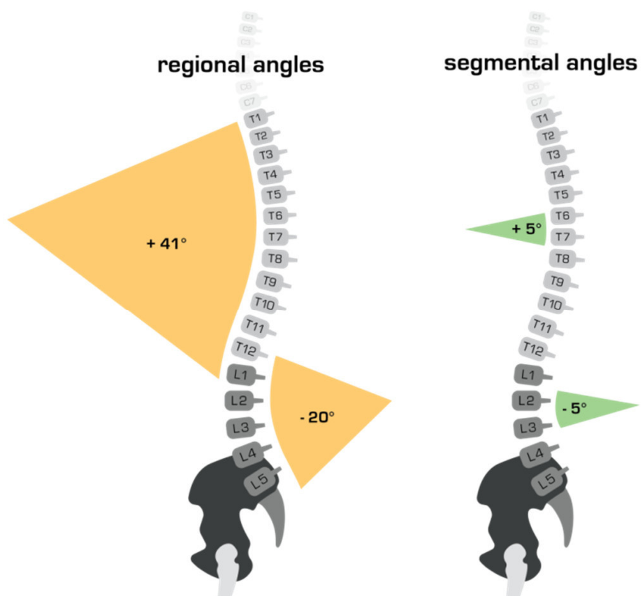

__Figure 10:__ Positive angles indicate kyphosis, and negative angles indicate lordosis in the sagittal plane of the spine. Graphics design by Sarah Tierney.

Pelvic tilt and vertical inclination were positive values towards flexion and negative values towards extension as relative to the true vertical axis.

2.5 Data manipulation

Data manipulation and analysis were done with Excel 2010 and 2013 (Microsoft Office Professional Plus 2010, Microsoft, Redmond, WA; Microsoft Office Professional Plus 2013, Microsoft, Redmond, WA), as well the Statistical Package for the Social Sciences (SPSS; IBM SPSS Statistics Version 25, IBM, Armonk, NY) was used for all statistical analysis.

Anthropometric data was collected in a semi-clothed state. In order to compare the knee height (sitting) to CFAS data, 30 mm was removed from the measurements to account for the boot heel. Anthropometric semi-clothed data was compared to the 2012 CFAS semi-nude database to see relative percentile ranges of participants within the male combat arms group for each body segment measured.

Statistical significance levels were corrected for Type I and Type II probability errors, the Benjamini-Hochberg correction (Benjamini-Hochberg, 1995) was used to determine the significant p value using Equation 1:

$$\left(\frac{i}{m}\right) * 0.05 \quad (1)$$

where i was the number of tests with a $p \leq 0.05$ and m was the total number of tests. Statistical significance was set at $p \leq 0.015$ as determined by the Benjamini-Hochberg correction (Equation 1) for the 217 tests accomplished, where 65 were $p \leq 0.05$.

2.5.1 Posture angles

Inertial accelerometers were not zeroed. Reference measurements were taken with participants sitting in an ISO 90 posture. For the C7 and L5 angles, the relationship of the X and Z axis determined the relative angle displacement from 90°. The Delsys® software (EMG Works 4.5.2, Delsys Inc., Natick, MA) reported X angles as negative values, and used the Z axis to determine if the accelerometer was leaning forward ($Z < 0$), or leaning backward ($Z > 0$) relative to -90° (Figure 11).

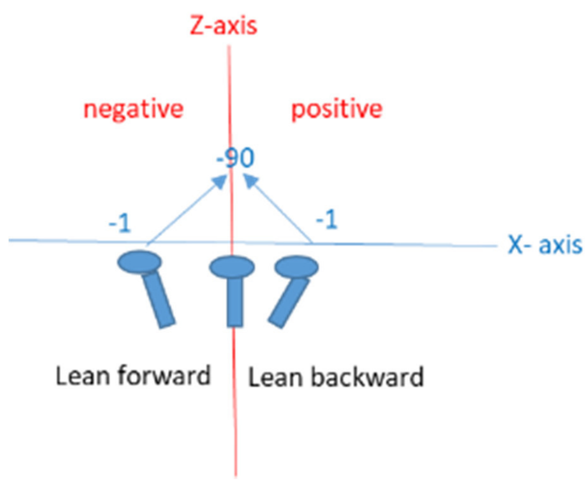

Figure 11: *Graphic depiction of accelerometer angle representation as relative to the upper torso and head (blue figures).*

Relative angles were calculated as the difference of the ISO 90 angle. The angles were transformed with Equation 2 in Excel:

```
=IF(AND($E$3<0,E17<0),90+($D$3-D17),IF(AND($E$3<0,E17>0),270+$D$3+D17,IF(AND($E$3>90,E17<=90),-90-($D$3+D17),IF(AND($E$3>90,E17>90),90-($D$3-D17),"ERROR"))))
```
(2)

Figure 12 shows an example of the angle transformation process in Excel.

```
fx =IF(AND($E$3<0,E5<0),90+($D$3-D5),IF(AND($E$3<0,E5>0),270+$D$3+D5,IF(AND($E$3>0,E5<0),-90-($D$3+D5),IF(AND($E$3>0,E5>0),90-($D$3-D5),"ERROR"))))
```

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Participant 11	Raw Data							Relative angles							
2	Condition	C7 X	C7 Z	L5 X	L5 Z	Th Y	Clf Y	Boot X	C7	L5	Th	Clf	Bt			
3	zero	-52	-52	-87	-88	2	8	0	90	90	0	0	0			
4	III_Px_Cbts	-54	-54	-71	71	-13	-5	2	92	112	14	14	2			
5	III_Px_FFOp	-53	-53	-71	72	-11	4	1	91	111	13	4	1			
6	III_Px_FFO	-59	-59	-73	74	-11	-2	2	97	109	13	11	2			
7	LORIT_Px_Cbts	-51	-51	-83	83	-3	14	0	89	100	4	-6	0			
8	LORIT_Px_FFOp	-55	-55	-89	89	-3	16	0	93	94	5	-8	0			

Figure 12: *Example of Excel transformation of body segment angles relative to ISO 90 posture (condition zero).*

The participant seated posture angles were grouped according to conditions; the group size was reported as n, the mean and standard deviation (stdev) were calculated for each accelerometer. The sagittal plane C7 and L5 angles were relative to 90° with <90° angles demonstrating a leaning torso forward posture, and angles >90° leaning torso backwards. The sagittal plane thigh angles were 0° relative to the horizontal plane, where a thigh angle >0° indicates a hip flexion posture, and a thigh angle <0° indicates a hip extension. The sagittal plane calf angles were considered 0° in the vertical plane, where calf angles >0° indicate a knee extension, and calf angles <0° indicate a knee flexion. The sagittal plane boot angles were considered 0° at the horizontal plane, with >0° indicating ankle flexion, and <0° indicating ankle extension.

Posture angles were analysed with a parametric test when data skewness and kurtosis were found to be acceptable. A non-parametric test was used when skewness and kurtosis were not acceptable (i.e., the skewness or kurtosis statistic was greater than twice the value of its standard error). Table 2 shows the tests used according to the comparison of data. For the Independent t-test, the Levene's test determined if the variance was equal, and the appropriate result was selected accordingly. Specific tests were noted in the text alongside the results.

Table 2: *Statistical tests according to data type.*

Comparison	**Parametric**	**Non-parametric**
Related data	Paired t-test (*t*)	Wilcoxon signed ranks (*T*)
Independent data	Independent t-test (*t*)	Mann-Whitney (*U*)

2.5.2 Spinal mouse angles

Paired t-test were used to determine the differences in spinal curvature with changes in leg position, as skewness and kurtosis were acceptable.

3 Results

3.1 Semi-clothed anthropometric data

As body segment measurements were taken with some clothes (i.e., t-shirt, boots, helmet), data was partly relative to the 2012 CFAS semi-nude measurements. Table 3 shows the minimum and maximum values for each semi-clothed body segment within the study participants. These values were compared to the male combat arms community of the 2012 CF anthropometric survey (Keefe et al., 2015). The combat arms group included infantry, artillery, combat engineers, and armoured trades. The study participant dimensions ranged between <1st and 99th percentiles of the combat arms group. However, it must be noted that semi-clothed dimensions (t-shirt, combat pants, sometimes helmets and boots) were different from semi-nude dimensions; the table below shows a relative comparison. Corrected knee height (sitting) and buttock to knee length were expected to be similar to CFAS findings. Stature, sitting height,[2] and weight in the semi-clothed condition were expected to be larger than CFAS findings.

Table 3: *Participant body segment range of dimensions with corresponding 2012 CAF combat arms percentile equivalents.*

	Participant dimensions (n = 58)		**Corresponding CAF combat arms percentile (n = 500)**	
	Minimum	**Maximum**	**Minimum percentile**	**Maximum percentile**
Weight (kg)[2]	55.4	113.7	<1	94
Stature (mm)	1621	1904	1	98
Sitting height (mm)	834	995	<1	97[3]
Knee height sitting (mm)	446	611	<1	99
Buttock to knee length, sitting (mm)[1]	563	654	5	90

[1]n = 57, [2]CFAS n = 499, [3]participants 1–28 were wearing helmets for sitting height.

3.2 Participant seated posture angles

The participants' seated posture angles were measured with inertial accelerometers positioned near the C7 and L5 vertebrae areas, as well as at the mid side of the right thigh, the mid side of the right calf and the toe end of the right boot (see Figure 7, Section 2.3.3).

3.2.1 Different LAV comparisons

Figure 13 shows the participant body mean angles and standard deviations (stdev) in the three seat positions of the three LAV vehicles while wearing the PPE with plates (PPEP). The PPEP clothing condition was selected for the LAV comparison analysis as it more closely represented operational conditions in the

[2] Participants 1–28 were wearing helmets during sitting height measurements.

combat theater. The variation between the participants' seated postures while sitting in the seats of the different vehicles showed 55% (5/9) of results were statistically significant ($p \leq 0.015$, indicated by **).

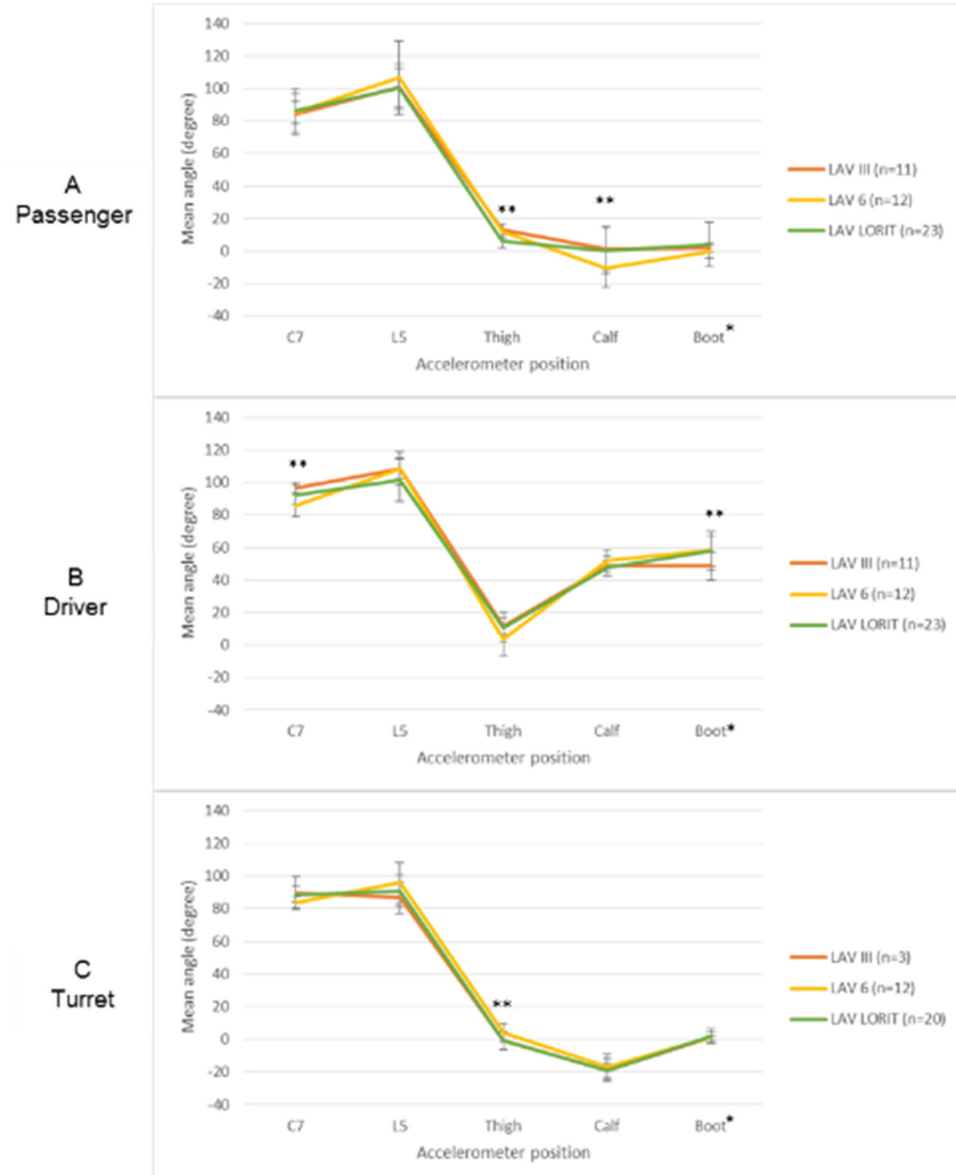

Figure 13: *Participant wearing PPEP seated posture group mean angles ± stdev while seated on the A) passenger, B) driver and C) turret seat of LAV. Statistical significance* $p \leq 0.015$ *denoted with **.*
**There was an accelerometer malfunction at the boot for one participant, n for LAV 6 and LAV LORIT at boot was one less than reported (i.e., Turret LAV LORIT n = 19 for boot).*

3.2.1.1 Participant postures while seated in passenger seat

A comparison of the participants' seated posture mean angles while sitting in the passenger seats of the different vehicles (Figure 13A) showed a statistically significant difference of the calf mean angles while seated in the LAV 6 (-10°±12°) compared to the LAV LORIT (0°±14°), (Wilcoxon signed ranks, $T = 6.00$, $p = 0.010$). The participant seated calf mean angle was in a knee flexion posture (calf tucking towards the thigh) in the LAV 6 where the LAV III and the LAV LORIT were at a neutral calf mean angle.

The participants' thigh mean angle while seated in the LAV LORIT passenger seat was decreased to closer to neutral (6°±4°) compared to the LAV III (13°±3°) ($T = 0.00$, $p = 0.003$), and LAV 6 (12°±4°) ($T = 4.00$, $p = 0.006$). The participants seated in the LAV LORIT passenger seat demonstrated a decreased hip flexion towards a horizontal angle of the thigh.

3.2.1.2 Participant postures while seated in driver seat

Within the driver seats of the three different vehicles (Figure 13B), the participants' boot mean angles while seated in the LAV III (49°±8°) showed a significantly decreased ankle flexion compared to the ankle flexion while seated in the LAV LORIT (58°±9°) (Paired t-test, $t(10) = -3.949$, $p = 0.003$). The larger boot mean angle indicated that the pedal of the LAV LORIT was placing the boot at an increased ankle flexion.

The participants' C7 mean angle while seated in the LAV 6 driver seat (86°±7°) was closer to neutral with a slight lean forward compared to sitting in the LAV III (C7 mean angle of 97°±3°, slight lean backward; Independent t-test, $t\ (16) = 5.181$, $p < 0.001$), and sitting in the LAV LORIT (C7 mean angle of 92°±6°, very slight lean backward, not statistically significant, $p = 0.121$).

3.2.1.3 Participant postures while seated in turret seat

The participant postures while seated in the turret seat of the different LAV (Figure 13C) showed a statistically significant difference within the thigh mean angle while seated in the LAV LORIT (-1°±5°), showing a slight hip extension, compared to sitting in the LAV 6, showing a slight hip flexion with a thigh mean angle of 4°±6° (Paired t-test, $t\ (11) = 3.388$, $p = 0.006$). The number of participants ($n = 3$) that were assessed in the LAV III turret seat were considered too few, and were excluded from this analysis.

3.2.2 Different seat comparisons within a LAV

The different seat configurations were different as the passenger seating consisted of bench seating with or without a backrest; for the LAV III and LAV 6, and the LAV LORIT had defined seats with a backrest (see Figure 2, Section 2.3.1). Similarly, the driver seats varied with their structure between the vehicles (see Figure 4, Section 2.3.1) and they were adjustable in many ways: seat pan angle and horizontal distance from the steering wheel, the backrest pivoted down to a fully reclined position, and pedals were all adjustable. The turret seats would be the most similar in that they both had a fixed seat pan and fixed backrest, however, the backrest angles (LAV 6 86° and LAV LORIT 97°) and seat pan angles (6° and 0°, respectively) were also visually different in their structures (i.e., seat cushions were different) (see Figure 5, Section 2.3.1).

Figure 14 shows the differences in participant seated postures within the different seats of a vehicle.

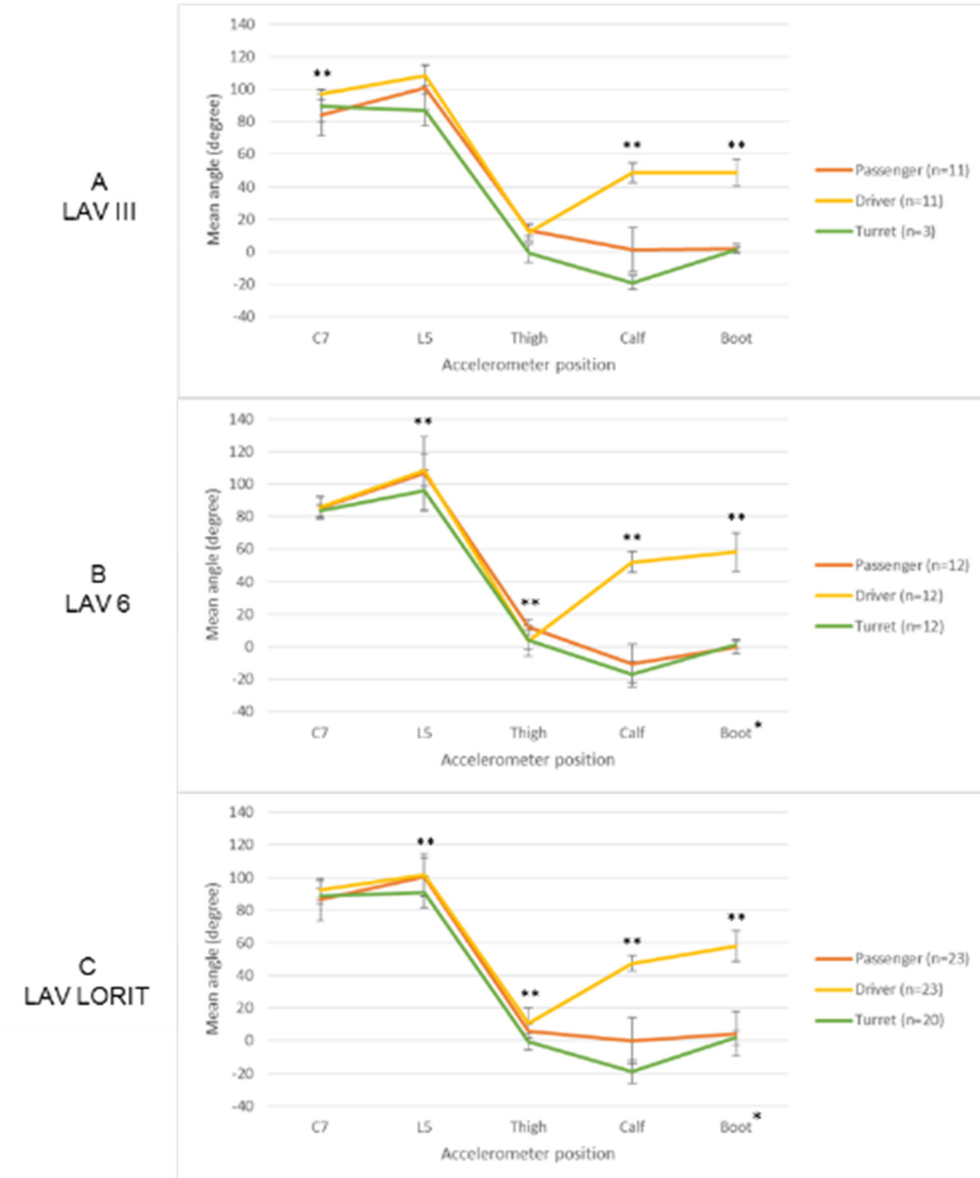

Figure 14*: Comparison of participant seated postures while sitting in different seats within a LAV and wearing PPEP. Group mean angles ± stdev reported. Statistical significance $p \leq 0.015$ denoted with **.*
**There was an accelerometer malfunction at the boot for one participant, n for LAV 6 and LAV LORIT at boot was one less than reported (i.e., Turret LAV LORIT n = 19 for boot).*

Statistical tests showed that participants' seated mean body angles differentiated significantly between the seats within a vehicle (Table 4), with all of the comparisons (7/7) showing at least one posture angle as being significantly different.

Table 4: *Statistical comparison of participants' seated body mean angles between seats of each LAV in the PPEP clothing condition. Driver (Dr), Passenger (Px), Turret (Tu).*

Vehicle	Test	Significant results ($p \leq 0.015$)		
		Dr vs. Px	**Dr vs. Tu**	**Px vs. Tu**
LAV III	Paired t-test	C7 calf boot	n/a	n/a
LAV 6	Wilcoxon signed ranks	calf boot	L5 calf boot	thigh
LAV LORIT	Wilcoxon signed ranks	calf boot	L5 thigh calf boot	L5 thigh calf

3.2.2.1 Participant postures in LAV III seats

Participant postures were compared while seated in the LAV III driver and passenger seats only as the turret seat evaluation in the LAV III had n = 3, statistical tests were inconclusive. The participants' C7 group mean angles, while wearing PPEP, showed that the driver seat was more reclined (97°±3°) compared to the passenger seat (84°±13°).

Participants' postures while seated in the LAV III driver seat showed large knee extension (49°±6°), and ankle flexion (49°±8°), compared to postures while seated in the LAV III passenger seat which showed neutral postures of the calf and boot mean angles (1°±14°, and 2°±3°, respectively).

3.2.2.2 Participant postures in LAV 6 seats

Participants' postures while seated in the LAV 6 driver seat showed large knee extension (52°±7°), and ankle flexion (58°±12°), compared to participants' postures while seated in the LAV 6 passenger seat which showed a knee flexion (-10°±12°), and a neutral boot mean angle (0°±4°).

The comparison between participants' postures while seated in the LAV 6 driver and turret seats showed a more pronounced knee flexion in the turret seat (-17°±8°), and a neutral boot mean angle (1°±3°). Participants' L5 mean angles seated in the turret seat showed a slight torso extension (96°±13°), while seated in the driver seat showed an L5 mean angle of 109°±10°, a larger torso extension.

The comparison between participants' postures while seated in the LAV 6 passenger and turret seats showed a more pronounced hip flexion seated in the passenger seat (12°±4°), and a neutral thigh mean angle in the turret seat (4°±6°).

3.2.2.3 Participant postures in LAV LORIT seats

The LAV LORIT showed the most differences in participant postures when sitting in the different seats. Participants' postures while seated in the LAV LORIT driver seat showed large knee extension (47°±5°), and ankle flexion (58°±9°), compared to participants' postures while seated in the LAV LORIT passenger seat which showed a neutral calf (0°±14°), and a close to neutral boot mean angle (4°±14°).

The comparison between participants' postures while seated in the LAV LORIT driver and turret seats showed a more pronounced knee flexion in the turret seat (calf mean angle of -19°±7°), and a neutral boot mean angle (2°±4°). Participants' L5 mean angles seated in the turret seat showed a neutral torso (91°±10°), while seated in the driver seat showed an L5 mean angle of 102°±13°, a torso extension. Participants' thigh mean angles while seated in the driver seat showed a mild hip flexion (11°±9°), which was significantly different from the very mild hip extension measured in the turret seat (-1°±6°).

The comparison between participants' postures while seated in the LAV LORIT passenger and turret seats showed a mild hip flexion while seated in the passenger seat (thigh mean angle 6°±4°) compared to the very mild hip extension. Similar to the driver and turret seating comparison, sitting in the LAV LORIT passenger seat resulted in a mild torso extension at the L5 mean angle (101°±12°), a significant difference from the neutral torso posture while in the turret seat. Participants' calf mean angles were different where sitting in the passenger seat showed a neutral calf (0°±14°).

3.2.3 Different clothing comparisons

Figure 15 shows the participant group mean posture angles ± stdev, while seated in the passenger seat, according to the different clothing conditions: baseline clothing (Condition 1), personal protective equipment (PPE) with plates (PPEP, condition 2B) and PPE no plates (PPE, Condition 2A). The Wilcoxon Signed Ranks test showed no statistically significant results. Figure 15C in the LAV LORIT did however show a trend. In the baseline clothing condition, the upper back mean angle (C7) was at 91°±5°. The addition of the PPE (FPV (no plates), helmet and tactical vest) moves the C7 mean angle slightly forward to 89°±8°. Once the ballistic plates were added (PPEP), the mean angle was reduced further to 87°±13° indicating a forward motion.

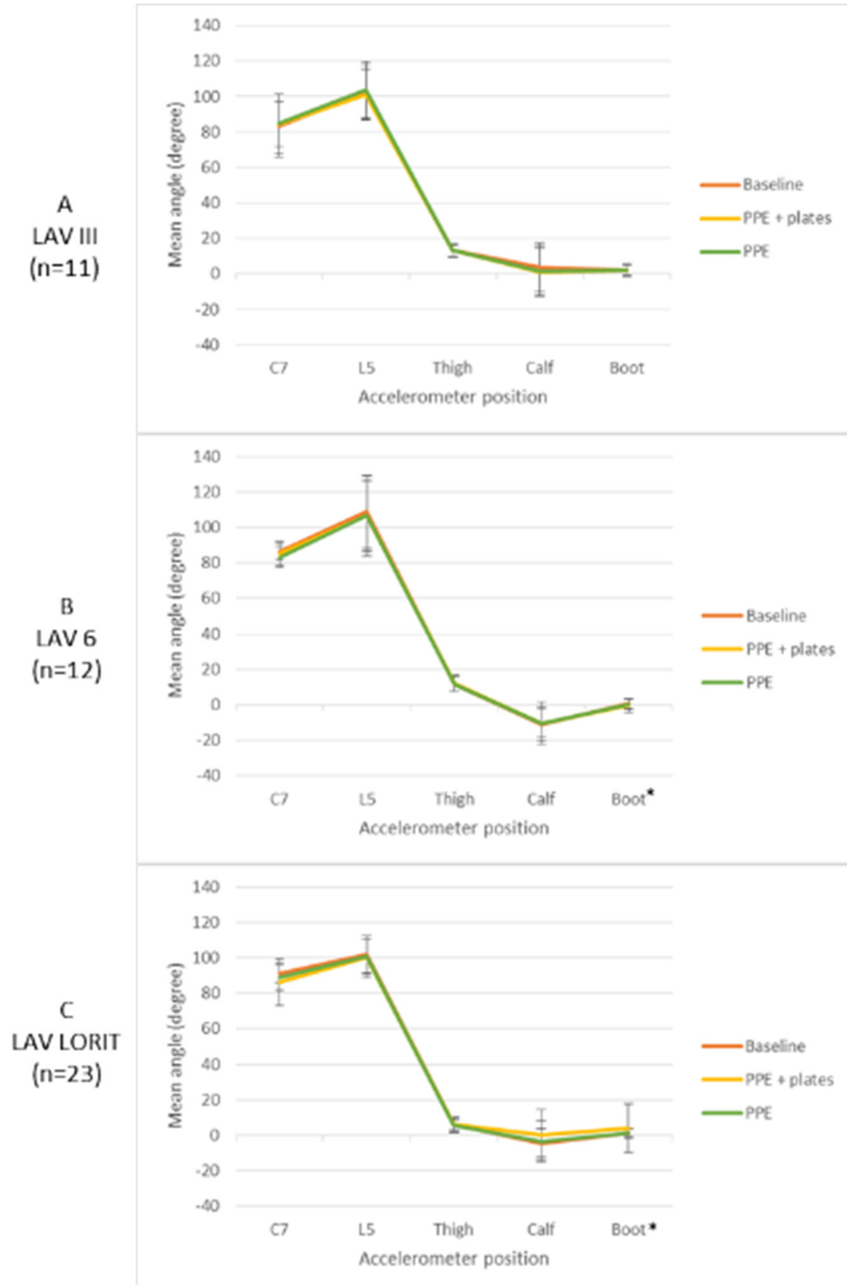

Figure 15: *Seated posture mean angles ± stdev in the passenger seat with different clothing conditions within the three vehicles assessed. *There was an accelerometer malfunction at the boot for one participant, n for LAV 6 and LAV LORIT at boot was one less than reported.*

Participant postures while wearing different clothing conditions were assessed in the driver seats of the three vehicles (Figure 16). The participant mean calf angles while seated in the LAV 6 driver seat were different when wearing the baseline (55°±6°) and PPEP (52°±7°) clothing conditions (Paired t-test, t(11) = 3.674, p = 0.004).

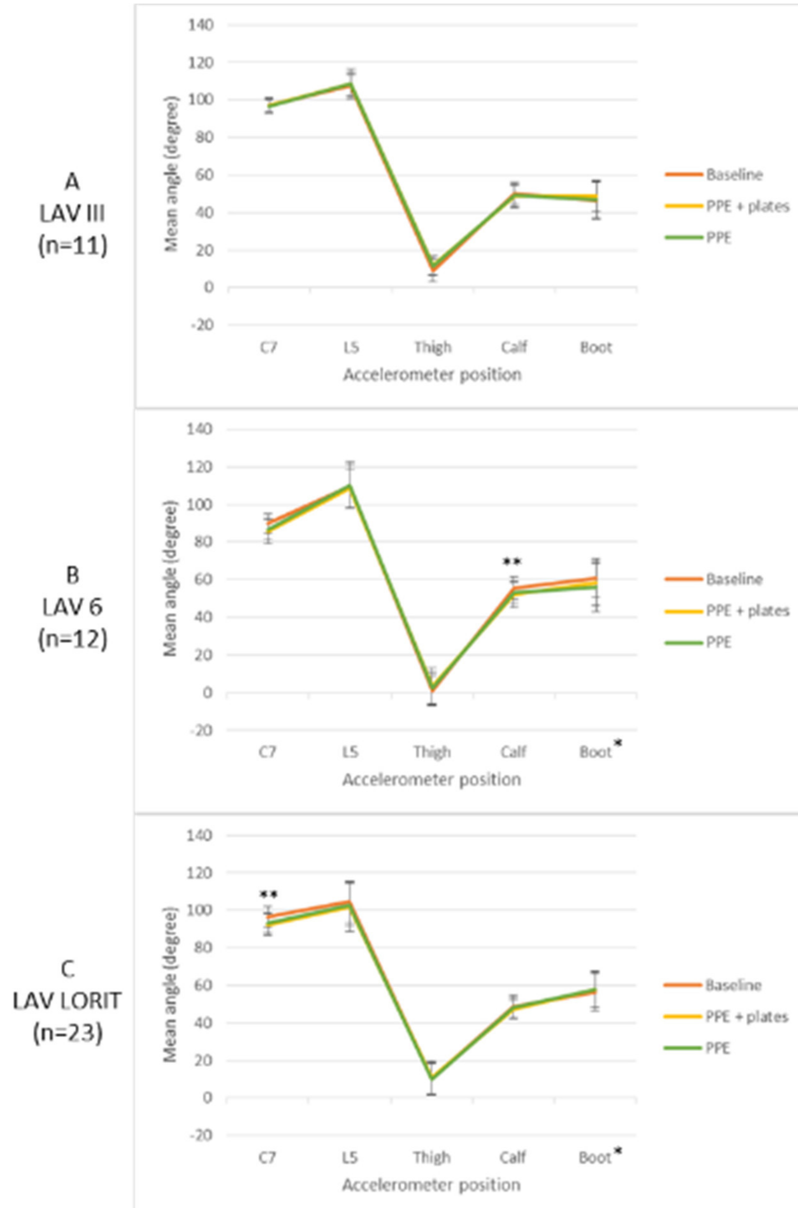

Figure 16*: Mean seated posture angles ± stdev in the driver seat with different clothing conditions within the three vehicles assessed. Statistically significant results (p ≤ 0.015) indicated with **. *A participant had a malfunction with the boot accelerometer, LAV 6 and LAV LORIT n values were reduced by one for the boot.*

Additionally, the C7 mean angles, while seated in the LAV LORIT driver seat, showed differences when comparing wearing baseline (96°±6°) and PPEP (92°±6°) ($t(22) = 4.013$, $p = 0.001$), as well as when comparing wearing baseline and PPE (93°±5°) ($t(22) = 3.881$, $p = 0.001$). This was the same trend that was seen in the LAV LORIT passenger seat where the upper body moved slightly forward with increasing levels of PPE.

The different clothing conditions were assessed in the turret seats of the three vehicles (Figure 17). The participants' C7 mean angles while seated in the LAV LORIT turret seat showed a significant difference between wearing the baseline and PPEP clothing conditions (Wilcoxon signed ranks test, T = 30.00, p = 0.005). This was a reversed effect from the previous trend where a decreased C7 mean angle was observed when wearing the baseline (85˚±8˚) and sitting further back when wearing the PPEP (89˚±5˚).

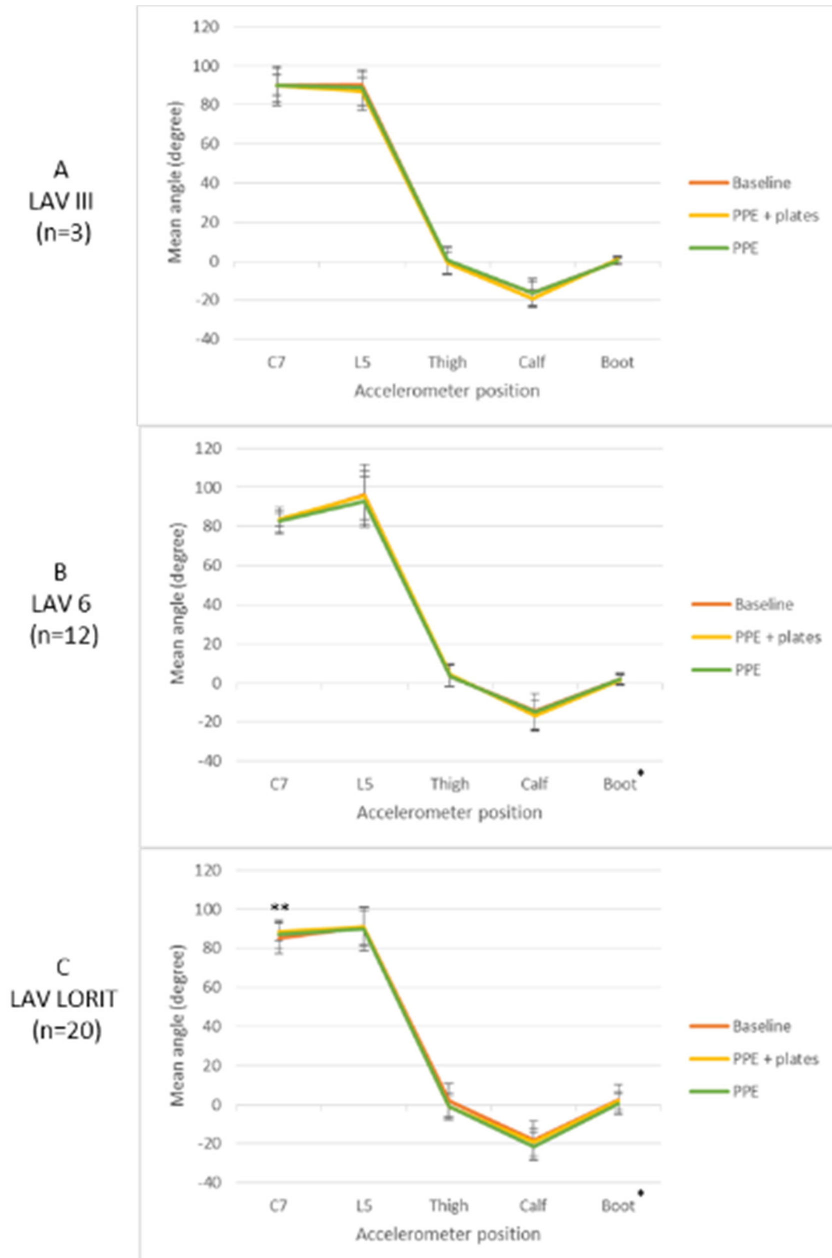

Figure 17: *Participant mean seated posture angles ± stdev while seated in the turret seat with different clothing conditions within the three vehicles assessed. Statistically significant results (p ≤ 0.015) indicated with **. *There was an accelerometer malfunction at the boot for one participant, n for LAV 6 and LAV LORIT at boot was one less than reported.*

3.2.4 Different leg positions

In the LAV LORIT passenger seat, participant body postural angles were measured with feet resting on footrests while wearing PPE with plates (PPEP). Figure 18 shows the group body segment mean angles ± stdev in the three different positions.

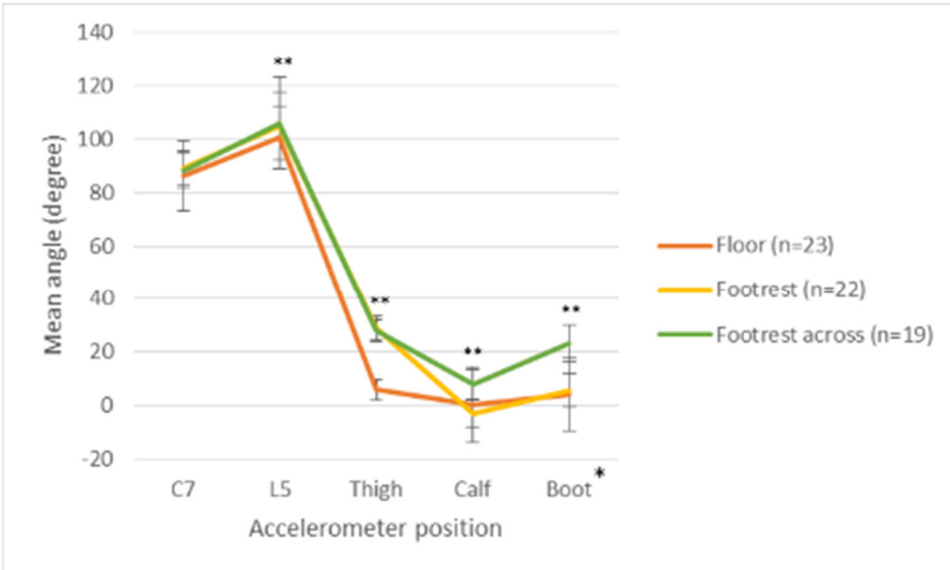

Figure 18: *Participant body mean angles ± stdev while seated in the LAV LORIT passenger seat with feet in different positions. Statistically significant results ($p \leq 0.015$) indicated with **. *There was an accelerometer malfunction at the boot for one participant, n for LAV 6 and LAV LORIT at boot was one less than reported.*

The Wilcoxon Signed Ranks test showed that body mean angles were different between the foot placements (Table 5).

Table 5: *Significant Wilcoxon Signed Ranks test results when comparing foot placement within the LAV LORIT passenger seat.*

Comparison	Significant results ($p \leq 0.015$)		
	Body angle	***T***	***p***
floor vs. footrest	L5	39	0.005
	Thigh	0	<0.001
floor vs. footrest across	Thigh	0	<0.001
	Boot	18	0.003
footrest vs. footrest across	Calf	0	<0.001
	Boot	0	<0.001

Considering the floor and footrest positions, the elevation of the feet and legs increased with the feet on the footrest which resulted in a more reclined posture at the L5 mean angle (105°±13°) compared to the L5 mean angle with feet on the floor (101°±12°). Additionally, the participant thigh mean angle with feet on the floor showed a slight hip flexion (6°±4°), and placing the feet on the footrest increased hip flexion (29°±5°).

Placing the feet on the floor and then moving to the footrest across showed the same pattern with the thigh mean angles (floor 6°±4° and footrest across 28°±4°) with an increased hip flexion created by the leg elevation. A similar effect was observed with the participant boot placement (4°±14°, and 23°±7°, respectively) an increased ankle flexion when feet were positioned on the footrest across. Though the L5 mean angle with feet placed on the footrest across (106°±17°) was similar to the L5 mean angle with feet on the footrest, the Wilcoxon test result was not considered statistically significant ($p = 0.024$).

The comparison of the footrest and footrest across postures showed a statistically significant change within the calf mean angles. Feet placed on the footrest created a slight knee flexion (-3°±5°), and moving the feet to the footrest across created a slight knee extension (8°±6°). The participant boot mean angles indicated that moving the feet from the footrest to the footrest across increased the ankle flexion significantly (6°±6°, and 23°±7°, respectively).

3.3 Seated spinal curvature

Seated spinal mouse data was compared between the different unsupported seated spine positions of lean back, neutral and lean forward, reporting the average ± standard deviation (stdev) in the sagittal plane. Initially we will look at the vertebrae sections, and then spine regions.

Figure 19 shows that at the neutral seated posture, mean vertebrate angles varied between -0.2° and 4.3°; the thoracic ranging from 0.3° to 4.3°, and the lumbar mean angles ranging from -0.1° and 2.1°. The lean back and forward postures showed the range of mobility of participants with mean angles ranging from 0.9° to 6.3° in the unsupported lean forward posture, and -1.8° to 6.0° in the unsupported lean back posture.

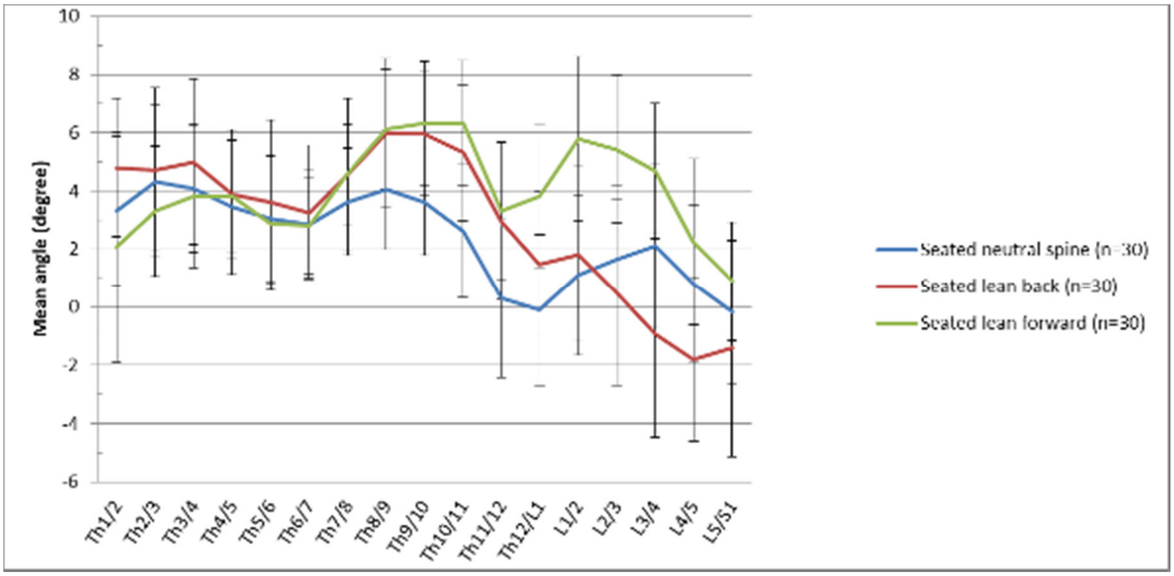

Figure 19: *Participant vertebrae section mean angles ± stdev of the thoracic (Th) and lumbar (L) vertebrae while seated in the unsupported neutral spine, lean back, and lean forward positions.*

Similarly, Figure 20 shows that the unsupported neutral seated posture had a pelvic tilt in slight extension (-4°±8°), the thoracic region showed a kyphotic angle (35°±9°, spinous processes diverging), a lumbar region in slight kyphosis (5°±9°), and a vertical inclination towards flexion (S1 to C7, 9°±8°).

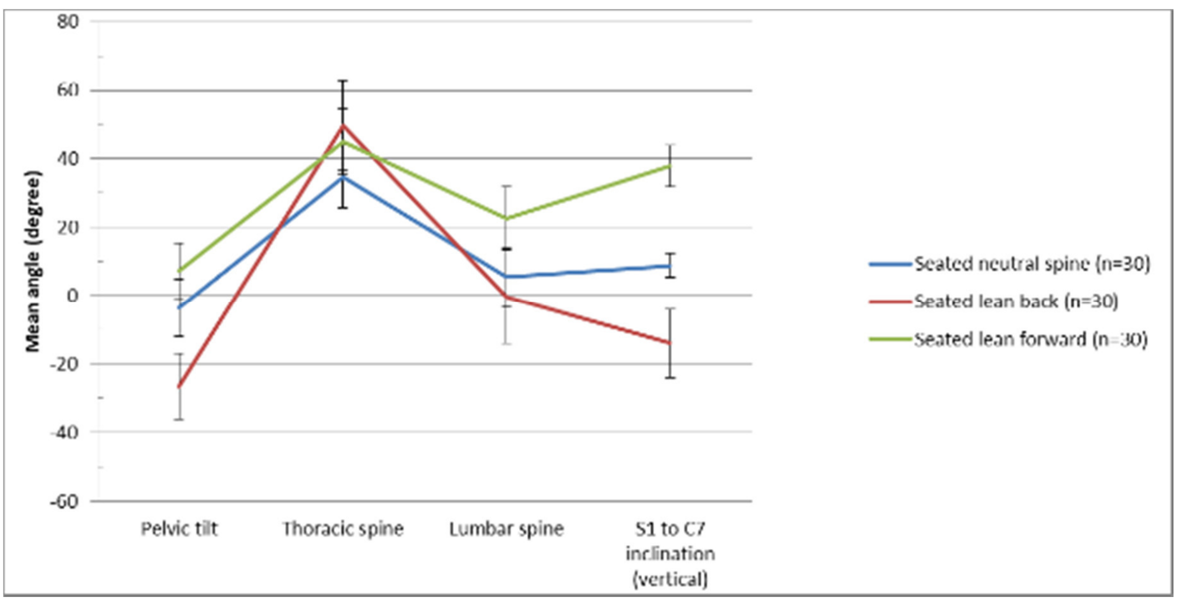

Figure 20: *Spinal region mean angles ± stdev with an unsupported neutral spine, lean back, and lean forward postures.*

The unsupported lean back posture resulted in an increased extension of the pelvic tilt (-27°±10°) and a vertical inclination (-14°±10°) in extension relative to the vertical axis (0°). An increased kyphosis in the thoracic spine (50°±13°) was observed, and the lumbar spine was neutral (0°±14°).

The unsupported lean forward position registered a positive pelvic tilt (7°±8°) and vertical inclination (38°±6°) confirming the torso flexion posture. The thoracic spine remains kyphotic (45°±10°), and the lumbar spine region (23°±9°) was rounded compared to the other postures into a kyphosis (spinal processes diverging).

Spinal length was decreased in the unsupported lean back position, and longer in the unsupported lean forward position compared to the neutral seated posture (Table 6).

Table 6: *Spinal mouse spine length results while seated in the* ***three spine positions.***

	Spine length (mm)		
	Average ± stdev	minimum	maximum
Lean back (n = 30)	581±40	499	648
Neutral (n = 30)	600±38	492	685
Lean forward (n = 30)	612±34	544	691

3.3.1 Elevated leg comparison

Participants were asked to raise their feet to 20° and 40° while seated unsupported with a neutral back while the spinal mouse measured the spinal curvature. The elevation of the legs to 20° increased the Th12/L1, L2/L3 and L4/L5 lumbar vertebrae segment mean angles by 2° compared to the neutral posture, with an increase of 3° at the L1/L2 segment (Figure 21).

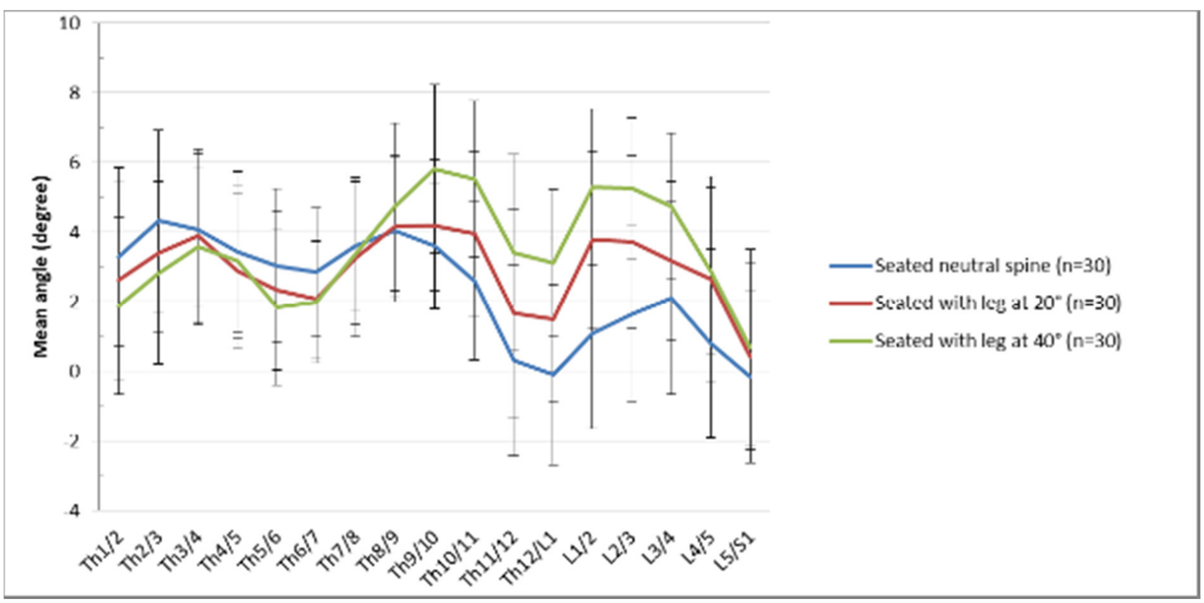

Figure 21: *Participant vertebrae section mean angles ± stdev of the thoracic (Th) and lumbar (L) vertebrae while seated in the unsupported neutral spine, and with legs elevated at 20° and 40°.*

Raising the legs to 40° increased the segment mean angles compared to the neutral posture by 2° at the Th9/10, and L4/5, a 3° increase at the Th10/11, Th11/12, Th12/L1 and L3/4 segments, and a 4° increase at L1/L2 and L2/3 segments, a general rounding of the spine towards kyphosis (spinal processes diverging) compared to a neutral spine.

Similar changes were seen in the dorsal region mean angles where the pelvic tilt extension reached -12°±7° and -22°±6° respectively with the 20° and 40° elevations, indicating an increased pelvic extension in reference to the true vertical axis (Figure 22).

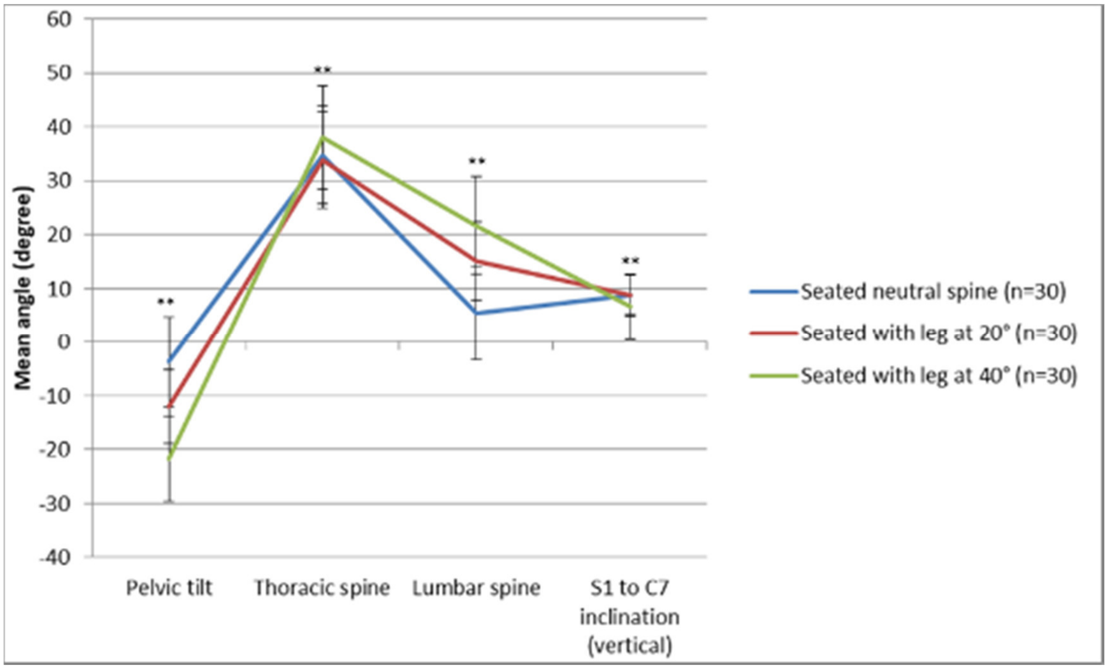

Figure 22: *Spinal region mean angles ± stdev with an unsupported neutral spine, and with legs elevated at 20° and 40°. Statistically significant results ($p \leq 0.015$) indicated with **.*

The participant lumbar region mean angles reached 15°±7° and 22°±7°, with 20° and 40° leg elevations respectively, shaping the lumbar spine towards kyphosis (spinal processes diverging). The thoracic spine region mean angle increased with the 40° leg elevation (38°±11°) compared to the neutral and 20° leg elevation, while the vertical inclination ranged between 7° and 9° in the three conditions, indicating a slight torso flexion was maintained in reference to the vertical axis.

Paired t-test showed statistically significant differences between the 3 leg positions for the pelvic tilt and lumbar spine within the three possible pairs (Table 7). Additionally, the vertical inclination showed an increased flexion in the 40° leg elevation condition compared to the neutral and the 20° leg elevation. The thoracic spine region showed an increased kyphosis with legs at 40° compared to legs elevated at 20°.

Table 7: *Statistically significant paired t-test results from spinal mouse measurements of spinal curvature.*

Comparison			Test	Significant results ($p \leq 0.015$) Body segment angle	*t (df)*	*p*
neutral	vs.	leg 20°	Paired t-test	Pelvic tilt	7.989 (29)	<0.001
				Lumbar spine	-8.854 (29)	<0.001
neutral	vs.	leg 40°	Paired t-test	Pelvic tilt	13.982 (29)	<0.001
				Lumbar spine	-10.650 (29)	<0.001
				S1 to C7 vertical inclination	2.983 (29)	0.006
leg 20°	vs.	leg 40°	Paired t-test	Pelvic tilt	12.253 (29)	<0.001
				Thoracic spine	-2.983 (29)	0.006
				Lumbar spine	-8.267 (29)	<0.001
				S1 to C7 vertical inclination	3.428 (29)	0.002

Participant mean spine length, while in the elevated leg postures, decreased slightly compared to the unsupported neutral posture (Table 8), similar to a lean back posture (Table 7).

Table 8: *Participant mean spine length while in an unsupported seated posture, and with 20° and 40° leg elevation postures.*

	Spine length (mm)		
	average ± stdev	minimum	maximum
Neutral (n = 30)	600±38	492	685
Leg 20° up (n = 30)	589±33	502	654
Leg 40° up (n = 30)	585±25	527	625

In general, the elevation of the legs rounded the lower portion of the back, tilted the pelvis towards extension, and the upper torso was pushed forward slightly.

4 Discussion

Participants represented well the male combat arms group representing the 1st to 98th percentile for most of the body segments, however, the anthropometry measures taken in this study were semi-clothed, and compared with semi-nude measures. Clothing effects may have influenced the larger percentiles with a relative estimate within the 95th percentile rather than 98th.

4.1 Participant seated posture angles

The participant seated posture mean angles reported from the five accelerometer positions (C7, L5, thigh, calf and boot) were compared to determine differences between the different vehicles, the different seats and the different clothing conditions. Reed et al. (1999) calculated body segment angles from joint coordinate measurements of the occupant using either a FARO Arm coordinate measuring device, or Science Accessories Corporation sonic digitizer probe. Future assessments could consider using this type of tool to determine joint locations, and calculate body segment angles rather than measuring the body segment angle directly as we have done in this study. However, as other research groups have used accelerometers and inclinometers successfully to measure seated body postures within an office environment, we believed that our assessment method was acceptable and informative (Mork and Westgaard, 2009; Mörl and Bradl, 2013). Our assessment was able to show differences among participant seated body postures while seated in different types of LAV, while seated in the different types of seats, while wearing different types of clothing, and while using different footrest postures.

4.1.1 Between LAV

A comparison of participant body posture angles, while seated in the three seat types, of the three different LAV assessed (LAV III, LAV 6 and LAV LORIT) showed statistically significant differences at $p \leq 0.015$. We offer possible explanations of the observed differences between the different LAV.

4.1.1.1 Seated in passenger seat

Participant body posture angles while seated in the passenger seat of the 3 different LAV showed statistically significant differences at the calf and thigh mean angles. While seated in the LAV 6, a negative calf mean angle indicating a knee flexion was observed. This knee flexion may have been influenced by the presence of a protrusion on the floor between the two benches in the LAV 6 (Figure 23A) that was absent in the LAV III and LAV LORIT (Figures 23B and C, respectively). Soldiers may have placed their heels closer to the bench; however, the boot mean angles were still registered as close to level (i.e., no ankle flexion due to toes on the protrusion and heels on the floor). The height of the protrusion in the LAV 6 floor may not have been large enough to increase the boot mean angle. Visually, the horizontal distance of the floor protrusion in the LAV 6 was not equal on both sides of the vehicle. The bench on the left side of the image showed a smaller gap between the bench edge than did the right side bench. The author was unaware of which side of the vehicle was used during data collection, and how this may have influenced the results.

Figure 23: *Floor area between passenger seating of A) LAV 6, B) LAV III, and C) LAV LORIT.*

The participant thigh mean angle while seated in the LAV LORIT passenger seat was close to level compared to the other two LAV. The LAV LORIT passenger seat pan may have been at a greater vertical distance from the floor, allowing the thighs to rest level on the seat pan compared to the bench seating of the LAV III and LAV 6. If the top of the benches were closer to the floor (i.e., shorter vertical distance), with feet on the floor, knees may have been higher causing a hip flexion as observed in Figure 23B.

The participants' C7 mean angles while seated in the passenger seats of the three different LAV did not show a difference, the three mean angles only showed a 3° difference. This was a surprising result as the bench seats would not be expected to produce a similar torso angle to a defined backrest like the LAV LORIT passenger seat.

4.1.1.2 Seated in driver seat

The driver seats were adjustable within the seat pan inclination, the backrest inclination, the horizontal distance of the seat pan, as well as the pedal height and horizontal angles, with a curved adjustment combining both pedal height and horizontal distance, within each LAV. Participants were asked to adjust the driver seat to their driving comfort, this said, paired assessments were considered comparable as the same participant adjusted the seat to their specific configuration in the LAV III and LAV LORIT, or LAV 6 and LAV LORIT vehicle comparisons. This was not true for the LAV III and LAV 6 comparison as these were two distinct groups of individuals, and seating adjustments were distinct to the individuals.

The participants' boot mean angle while seated in the LAV III driver seat was different compared to the LAV LORIT driver seat, suggesting that the pedal adjustment systems may have been different between these 2 vehicles. The LAV III pedal system may have been adjusted further away in the horizontal direction and reduced the ankle flexion or the inclination angle of the pedal system created a reduced ankle flexion.

While seated in the LAV 6 driver seat, the participants' C7 mean angle was more upright (slight lean forward) compared to the LAV III (slight lean back). As the backrest was adjusted by the participants for their comfort, this may have influenced this finding. The LAV III and LAV 6 participants were independent from each other (i.e., not paired) it may simply have been that the participants in the LAV 6 group had a tendency to set the backrest more upright. Considering both the LAV III (n = 11) and LAV 6 (n = 12) groups were assessed in the LAV LORIT (n = 23), we saw that the participants' C7 mean angle while seated in the LAV LORIT driver seat was in between the LAV III and LAV 6 mean angles, supporting the possibility that participant preference of the backrest setting influenced the observed result. Additionally, the horizontal distance of the backrest away from the steering wheel may have influenced the backrest setting; the steering wheel in the LAV III may have projected out further than the LAV 6 steering wheel.

As well, participants may have been required to set the backrest at this angle to align their eyes with the episcope or the driver visual aid (DVA) to ensure adequate vision through the scope, and the episcope placement in relation to the seat pan and backrest may have varied between the LAV III and LAV 6.

The LAV comparisons were assessed with the PPEP (PPE with plates) clothing condition as it was more closely related to the operational environment. The presence of the ballistic plate in the fragmentation vest may also have influenced the participants' more upright C7 mean angle if the backrest cushion was denser in the LAV 6 compared to the LAV III backrest cushion, resulting in the participant being pushed forward. The effects of the clothing will be discussed in more detail in Section 4.1.3.

4.1.1.3 Seated in turret seat

The turret seats could be elevated allowing the crew commander and the gunner to have their heads outside the roof hatch when opened; the seat pan could be elevated to a point where all of the weight of the thighs was resting on the seat pan. It was unknown if the turret seats were fully down during the data collection, or if the seat vertical height was set by participants. At the lowest setting, the turret seat was accessible from the inside of the vehicle.

While seated in the LAV 6 turret seat, participants had a slightly larger thigh mean angle than when seated in the LAV LORIT turret seat. The turret seat pan angles were measured at 6° in the LAV 6 and 0° in the LAV LORIT. The larger seat pan angle of the LAV 6 increased the participants' thigh mean angles. Additionally, the LAV LORIT turret seat pan design has a lower front edge (Figure 24B) that may have lowered participant thigh mean angles further, increasing the difference between the two vehicles.

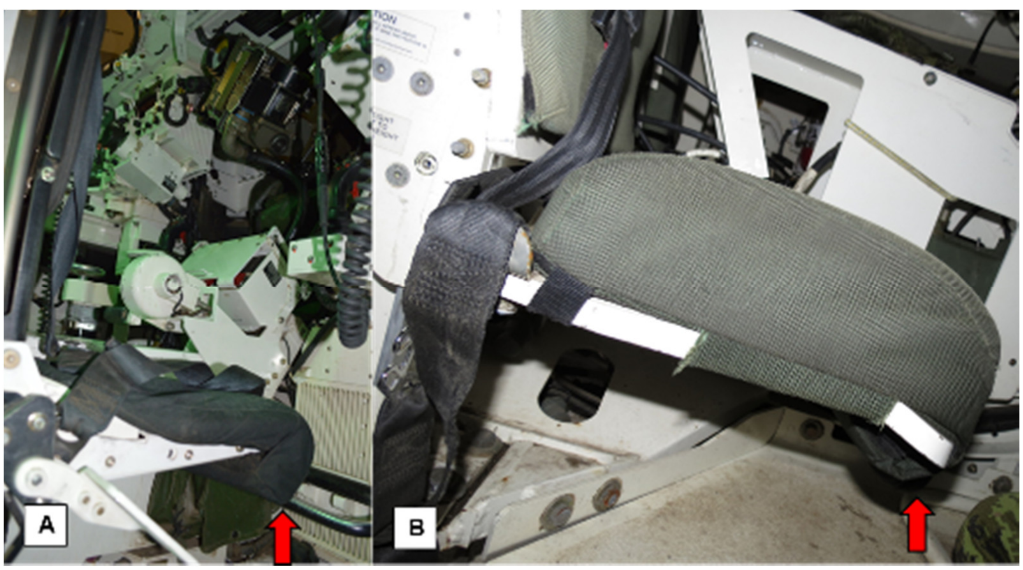

Figure 24: *Turret seat pan design differences in the A) LAV 6, and B) LAV LORIT.*

4.1.2 Between seats within a vehicle

The differences between the passenger, driver and turret seats within a single vehicle were very different as the seats all had different function, purpose and design. The driver seat was the most adjustable. The turret seat pan and backrest were not adjustable, but the seat pan vertical distance from the floor was adjustable in order to have the soldier lifted outside the vehicle roof hatch as desired and as required by the mission. The passenger seats were much less adjustable; however, the backrest portion of the bench style seating could be removed according to the mission to allow for more storage space. This said, the storage area behind the bench seat could be filled with equipment and be used as a backrest. The LAV LORIT passenger seat was not adjustable; however, there were 3 foot placement options: the floor, the seat footrest, and the footrest on the seat across. All of these differences within the seat designs were identified with participant posture mean angle comparisons, where all 7 comparisons found at least one body segment mean angle with a statistically significant difference (see Table 4, Section 3.2.2).

The greatest number of participant posture angle differences within a single vehicle was the LAV LORIT seat comparisons, only the participants' C7 mean angles were not statistically different, suggesting that these three seat designs were unique to their designated tasks, and that they had similar backrest angles.

4.1.2.1 Sitting in driver seat compared to passenger seat

Differences were found, not surprisingly; at the participants' calf and boot mean angles (knee extension and ankle flexion, respectively) while seated in the driver seat compared to sitting in the passenger seats, presumably due to the pedals that the driver had accessed. This pattern was seen in all three vehicles.

Within the LAV III, the participants' C7 mean angle was leaned back in the driver seat compared to the passenger seat, possibly due to participants' backrest angle adjustments. At the same time, the bench style passenger seat may have encouraged participants to lean forward.

4.1.2.2 Sitting in the driver seat compared to turret seat

The difference observed between the participants' calf and boot mean angles while seated in the driver and turret seats were larger still than the driver and passenger comparison. The turret seat design encouraged a knee flexion. Figure 24 shows that the LAV 6 turret seat pan front edge has padding folding under (Figure 24A), and the LAV LORIT turret seat pan tilts downwards at the front edge (Figure 24B). Both these seat designs, and the seat pan angles (6° and 0°, respectively), may have encouraged participants to place their feet under the seat and increased knee flexion. The knee flexion while seated in the turret seat increased the difference with the knee extension while seated in the driver seat.

The participants' L5 mean angles showed a reclined posture in the driver seat, with the adjustable backrest, compared to the turret seat in both the LAV 6 and LAV LORIT. The participants' L5 mean angles while seated in the turret seat were more upright, reflective of the backrest design which was attached to the elevating column. Turret backrest angles were 86° (LAV 6), and 97° (LAV LORIT), where the driver backrest angles in the LAV 6 could be adjusted from 74° to 168°.

Within the LAV LORIT, the participants' thigh mean angles while seated in the turret seat were close to neutral compared to the driver seat. As previously mentioned, the turret seat pan design of the LAV LORIT may have increased hip extension with the neutral seat pan angle, and the front edge of the seat pan dipping down. Additionally, the driver seat pan angle was adjustable, and participants seemed to prefer a slight hip flexion to potentially better access the driving pedals. The horizontal distance of the driver seat with the pedals could also have influenced hip flexion.

4.1.2.3 Sitting in the passenger seat compared to turret seat

The participants' thigh mean angles were different while seated in the turret compared to sitting in the passenger seats in both the LAV 6 and LAV LORIT (the LAV III had an $n = 3$, hence inconclusive). The participants' mean thigh angles while seated in the turret seat were close to neutral, suggesting that the seat pan of those seats were supporting the upper leg. The participants' mean thigh angles while seated in the passenger seats of the LAV 6 and LAV LORIT both showed a mild hip flexion suggesting that the knees were higher than the seat pan, this was expected for the bench type seating of the LAV 6, however, the LAV LORIT passenger seat had a dedicated seat pan and backrest. The LAV LORIT passenger seat pan angle was measured at 3° which could explain the slight hip flexion when feet were positioned on the floor.

The participants' L5 mean angles were more reclined while seated in the LAV LORIT passenger seat compared to sitting in the turret seat. The turret backrest angle was 97°, while the backrest angle of the passenger seat was 106°, the backrest angles influenced the differences in participant postures.

The participants' calf mean angles showed an increased knee flexion while seated in the LAV LORIT turret seat compared to sitting in the LAV LORIT passenger seat. The increased knee flexion was previously proposed to result from the turret seat design, where the front edge of the seat was dipping downward (Figure 24).

4.1.3 Between clothing conditions

There were no statistically significant differences ($p \leq 0.015$) in participant body postures between the three clothing conditions while sitting in the passenger seats of all three LAV. However, we did see a trend in participants' C7 upper back mean angles while seated in the LAV LORIT passenger seat. The LAV LORIT passenger seat had a distinct backrest compared to the bench seating of the LAV III and LAV 6. The backrest structure may be pushing the passenger forward with the addition of PPE, more so in the presence of the ballistic plates. The dense material of the backrest may not have allowed the ballistic plates to sink into the backrest, resulting in a slight flexion of the upper back (Figure 15C, Section 3.2.3).

The participants' C7 mean angle when wearing PPE ± plates was less reclined while seated in the LAV LORIT driver seat than when wearing the baseline clothing condition. The LAV LORIT driver seat backrest had less cushioning than the other two LAV driver seats (Figure 4, Section 2.3.1). It was possible that the extra bulk from the fragmentation protective vest (FPV) and ballistic plate were pushing the participant more forward in the LAV LORIT driver seat, where the more flexible cushions of the LAV III and LAV 6 were absorbing most of the displacement created by the FPV and the rear ballistic plate.

The participants' calf mean angle was smaller when wearing PPEP compared to the baseline clothing conditions, while seated in the LAV 6 driver seat. Potentially, the PPEP clothing condition may have pushed the participants' buttocks horizontally forward on the seat pan, which in turn may have pushed the knee horizontally forward. As the pedal placement would not have been modified between these clothing conditions, the distance to the pedals from the knee would have decreased when wearing the PPEP decreasing participants' calf mean angles.

Reed and Ebert (2013) used a whole-body 3D laser scanner to capture standing and seated postures of soldiers with three levels of garb in a simulated laboratory environment. In their driver seat, when the fragmentation vest was added, and further influence from the loaded tactical vest, they observed:1) an aft shift in the seat position (horizontal axis), 2) the hip shifted forward, 3) the hip-eye-angle was more upright,

4) the hip to eye distance was greater suggesting that the body armour reduced the lumbar spine flexion slightly, 5) the eye location in reference to the H-point was higher, and 6) the driver eye location was more forward. These results support our observations for both the participants' C7 and calf mean angle changes that occurred in the presence of PPEP.

Participants' C7 mean angles were different when comparing baseline and PPEP clothing conditions while seated in the LAV LORIT turret seat. The effect was opposite from previous observations in that the participants' C7 mean angle while wearing PPEP showed the **torso leaning back** slightly towards neutral compared to wearing the baseline clothing condition. The turret seat of the LAV LORIT and LAV 6 visually had differences in their backrest design, the LAV LORIT had a thicker portion at the mid- to low-back area padding (Figure 25B).

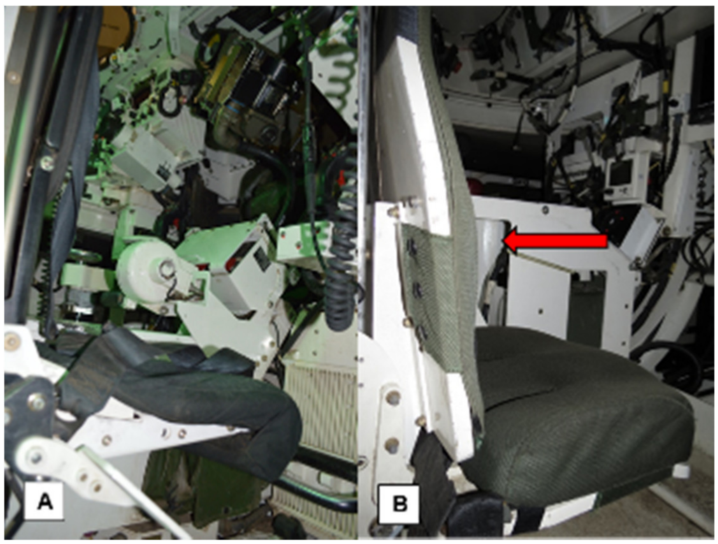

Figure 25: *Backrest of turret seat in A) LAV 6, and B) LAV LORIT.*

The bottom edge of the rear ballistic plate within the FPV sat at the Th12/L1 area of the back. Potentially, when wearing the PPEP, the lower portion of the ballistic plate may be pushed forward by the LAV LORIT turret seat backrest padding, and angling the soldiers' upper back against the upper thinner cushion of the backrest as if a pivot were in the middle of the ballistic plate. The LAV 6 turret seat backrest did not seem to have a thicker portion in the mid-back area (Figure 25A). It was also possible that the ballistic plate extended over the top edge of the LAV LORIT turret seat backrest as it did in the LAV 6 turret seat (Figure 26). The C7 mean angle may also have been influenced by the sight alignment with participants' eyes.

***Figure 26**: Interaction of rear ballistic plate with LAV 6 turret seat backrest in the gunner position.*

In their crew postures, Reed and Ebert (2013) observed that the PPEP with the tactical vest reduced torso recline, as measured by the hip eye angle, when the seat had a 10° recline. However, for most measurements, there were no significant differences and their modelling corrections were limited to the baseline combat uniform measurements. It must be noted that the crew mock-up was a cushioned seat with a defined seat pan and adjustable backrest, different from our passenger and turret seats. Reed and Ebert (2013) also looked at 3D body shape data, the effects of garb in this portion of their study highlighted that their PPEP and tactical vest had the most influence at the mean abdomen area depth showing increases of 56 mm with PPEP, and 244 mm with the tactical vest. These differences were reported as being independent of participant body sizes, and were due to the equipment.

4.1.4 Foot placement comparison

Moving participant feet from the floor up onto footrests showed differences in participants' leg postures and the low back (L5 mean angles). Elevating the feet onto the seat footrest increased the participants' L5 mean angles, however the participants' C7 mean angles remained the same. Presumably there was a rounding of the lumbar portion of the back, and an increased extension of the pelvic tilt to create the torso extension, and the LAV LORIT passenger seat backrest supported the upper back. The increased hip flexion was expected as the knees were pushed vertically up by the footrest.

When comparing participant posture mean angles while feet were placed on the floor and then moved to the footrest across, the participants' thigh mean angles showed an increased hip flexion presumably due to the vertical movement of the knee. The participants' L5 mean angles with feet on the floor and the footrest across showed a similar change in posture though not statistically significant ($p = 0.024$) as statistical significance was corrected to $p \leq 0.015$. Placing the foot on the footrest across increased the participants' ankle flexion presumably due to the larger horizontal distance from the seat edge to the footrest across (Figure 3, Section 2.3.1).

Moving the feet from the footrest on the seat to the footrest on the seat across influenced the participants' calf and boot mean angles. Participants were in a knee flexion posture with their feet on the footrest, while the knee was extended to reach the footrest across due to the increased horizontal distance between the two footrest positions. Similar to the participants' boot mean angles, the larger horizontal distance between the footrests increased ankle flexion (Figure 3, Section 2.3.1).

4.2 Seated spinal curvature

Participants' seated neutral spinal curvature showed a neutral to slightly kyphotic lumbar spine (4°±9°), and a slight extension of the pelvic tilt (-2°±8°), these relative angles were similar to other studies. De Carvalho et al.'s (2010) radiographic study of the standing and seated spine in the sagittal plane reported that seated sacral tilt[3] was -1° and seated lumbar lordosis was 20°[4] while seated in a car driver seat. The support of the car driver seat in their study influenced the posture of the lumbar spine. The absence of lumbar support in our study influenced the neutral to slightly kyphotic result that was observed. The sacral tilt resulting from the act of sitting was similar in both studies. Additionally, a study that looked at supported and unsupported seating postures with radiography did observe lumbar lordosis differences relative to the presence or absence of back support (Cho et al., 2015). They reported lumbar lordosis differences ranging from 36° and 18°[5] with posterior support, and changing to 1° more neutral on a stool, and -5° to -7° in lumbar kyphosis without posterior support. Seated lumbar mean angles measured by an optical tracking system were reported to be at -8°±9° in the correct sitting posture (slight lumbar lordosis), and 4°±9° (slight lumbar kyphosis) during a 10 minute sitting period (Claus et al., 2016). Vergara and Page (2000) looked at different uses of the backrest of an office chair using a rachimeter. Their work showed pelvic tilt in extension in the seated postures, and the lumbar lordosis increased with the use of back support.

These differences observed with other techniques support the results that we obtained with the spinal mouse tool. Furthermore, when we look at the changes that occurred with legs elevated, the largest differences were at the lumbar spine and the pelvic tilt. Lumbar kyphosis increased with increasing leg elevation. Cho et al. (2015) observed their largest lumbar kyphosis when participants were sitting cross-legged.

Other studies that looked at cyclist and kayaker postures also used the spinal mouse tool (Muyor et al., 2011; Lopez-Minarro et al. 2012b). They reported pelvic tilt in extension while sitting on a cycle seat, and in a kayak, and also reported lumbar kyphosis while in forward leaning postures of both cycling and kayaking.

The L5 accelerometer and spinal mouse tool were both able to detect the torso extension resulting from leg elevations onto the footrest. As the spinal mouse could not be used in the vehicle seats, the accelerometers may be useful in partially defining lumbar lordosis while seated.

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[3] De Carvalho et al. (2010) described "Sacral tilt was measured as the angle formed between a line drawn parallel to the posterior aspect of the S1 vertebral body with a true vertical line."

[4] 20° lumbar lordosis in De Carvalho et al. (2010) is equivalent to -20° spinal mouse measurements as referenced to lordotic angles in the sagittal plane.

[5] Positive angles from Cho et al. (2015) would be negative angles with spinal mouse definitions of lordosis angles in the sagittal plane, and negative angles from Cho et al. (2015) would be positive angles with spinal mouse definitions.

4.3 Limitations

The author was not included in the data collection nor in the study preparation. The author was given the data and guidelines on what had occurred during the study. The previous principal investigator (co-author Capt Tommy Poirier) was unavailable to clarify queries and the current author has made logical assumptions according to the information obtained.

It was assumed that the passenger bench backrest was removed during data collection, and the storage area was partly empty throughout the study when assessing the bench style seating of the LAV III and LAV 6. Only a few images were found, and these showed that the bench back was removed, and that the storage behind the bench was empty.

During this study, participants were not asked to buckle their seat restraints. Seat restraints were available for the driver seat, turret seat, and the LAV LORIT passenger seat. Soldier seated postures may be different when wearing seat restraints. Additionally, the author was unaware if participants were asked to sit upright rather than comfortably, or at their leisure (i.e., a more realistic posture) during the study data collection.

The spinal curvature could not be measured with clothing, hence the influence of PPE on spinal curvature could not be determined. It was also not possible to see the influence of the presence or absence of a backrest on the seated posture spinal curvature.

This study was limited by the fact that there were no female participants. Females were not excluded from the study, however, none were available as participants either.

Data collection within the vehicles occurred over a short period of time. It is expected that seated postures would more than likely change when soldiers were in the vehicle for hours rather than a few minutes. Soldier fatigue also has the potential to influence seated postures, after a long patrol at the end of the day, seated postures may be very different to the postures observed with rested participants.

The study measurements were taken with one soldier at a time, having a full passenger capacity, 7 to 8 soldiers, will reduce the available seating space, this may also influence soldier posture. In the LAV III and LAV 6, with the passenger bench type seating, soldier and mission equipment would be stored behind the benches, and could be used as backrests. As the quantity and the placement of equipment was potentially different with each mission, soldier postures may in turn change as a function of the equipment and the mission. Similarly, in an empty passenger area, soldiers may take advantage of the empty seat in front of them, and put their feet up, and position themselves in a semi-reclined posture, or they may have knees falling to the sides.

Accelerometers were attached to the skin, and the stability of skin may have been different from one participant to the next, as well as from one area of the body compared to another. The skin on the lower back may have moved more easily than at the C7 for instance. The movement of the accelerometers may have influenced accelerometer measurements.

5 Conclusion

We were able to logically explain the posture differences that were observed in the different seats and vehicles, while wearing different clothing conditions. The inertial accelerometers were able to successfully determine body mean angle differences, and that this technique had merit. Other techniques such as shape tape, and the FARO arm, have since been proposed and these will be considered to determine how we should proceed with future studies.

The spinal mouse tool was also effective at measuring spinal curvature, however its use in determining differences in supported seated postures and in clothing conditions was limited. Future studies are planned to use an adjustable seating system exposing the spinal column to assess supported seated spine curvature with the spinal mouse tool. The intent was to also evaluate the effect of clothing with specialised clothing items that would still allow access to the bare spinal column.

References

Benjamini, Y. and Hochberg, Y. (1995), Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B (Methodological).* 57(1), 289–300.

Cho, I.Y., Park, S.Y, Park, J.H, Kim, T.K., Jung, T.W. and Lee, H.M. (2015), The effect of standing and different sitting positions on lumbar lordosis: radiographic study of 30 healthy volunteers. *Asian Spine Journal*. 9(5), 762-769.

Claus, A.P., Hides, J.A., Lorimer Moseley, G., Hodges, P.W. (2016), Thoracic and lumbar posture behavior in sitting tasks and standing: Progressing the biomechanics from observations to measurements. *Applied Ergonomics.* 53, 161–168.

De Carvalho, D.E., Soave, D., Ross, K. and Callaghan, J.P. (2010), Lumbar spine and pelvic posture between standing and sitting: a radiologic investigation including reliability and repeatability of the lumbar lordosis measure. *Journal of Manipulative and Physiological Therapeutics*. 33(1), 48–55.

Guermazi, M., Ghroubi, S., Kassis, M., Jaziri, O., Keskes, H., Kessomtini, W., Ben Hammouda, I. and Elleuch, M-H. (2006), Validity and reliability of spinal mouse to assess lumbar flexion. *Annales de réadaptation et de médecine physique.* 49(4), 172–177.

Hotzman, J., Gordon, C.C., Bradtmiller, B., Corner, B.D., Mucher, M., Kristensen, S. Paquette, S. and Blackwell, C.L. (2011), Measurer's handbook: US Army and Marine Corps anthropometric surveys, 2010–2011, U.S. Army Natick Soldier Research, Development and Engineering Center. NATICK/TR-11/017.

Keefe, A., Angel, H. and Mangan, B. (2015), 2012 Canadian Forces anthropometric survey (CFAS)—Final Report. Defence Research and Development Canada. Scientific Report, DRDC-RDDC-2015-R186.

Lopez-Minarro, P.A., Muyor, J.M., Belmonte, F. and Alacid, F. (2012[a]), Acute effects of hamstring stretching on sagittal spinal curvatures and pelvic tilt. *Journal of Human Kinetics.* 31, 69–78.

Lopez-Minarro, P.A., Muyor, J.M. and Alacid, F. (2012[b]), Influence of hamstring extensibility on sagittal spinal curvatures and pelvic tilt in highly trained young kayakers. *European Journal of Sport Science*. 12(6), 469-474.

Mannion, A.F., Knetch, K., Balaban, G. Dvorak, J. and Grob, D. (2004), A new skin-surface device for measuring the curvature and global and segmental ranges of motion of the spine: reliability of measurements and comparison with data reviewed from the literature. *European Spine Journal.* 13(2), 122–136.

Mork, P.J. and Westgaard, R.H. (2009), Back posture and low back muscle activity in female computer workers: A field study. *Clinical Biomechanics*. 24(2), 169–175.

Mörl, F., and Bradl, I. (2013), Lumbar posture and muscular activity while sitting during office work. *Journal of Electromyography and Kinesiology.* 23(2), 362–368.

Muyor, J.M., Lopez-Minarro, P.A. and Alacid, F. (2011), Spinal posture of thoracic and lumbar spine and pelvic tilt in highly trained cyclists. *Journal of Sports Medicine.* 10(2), 355–361.

NATO (2007), Test methodology for protection of vehicle occupants against anti-vehicular landmine effects. Research and Technology Organisation Technical Report. RTO-TR-HFM-090.

Reed, M.P., Manary, M.A. and Schneider, L.M. (1999), Methods for measuring and representing automobile occupant posture. *SAE Technical Paper Series.* 1999-01-0959.

Reed, M.P. and Ebert, S.M. (2013), The seated soldier study: posture and body shape in vehicle seats. University of Michigan Transportation Research Institute. UMTRI-2013-13.

Vergara, M. and Page, A. (2000), System to measure the use of the backrest in sitting-posture office tasks. *Applied Ergonomics.* 31(3), 247–254.

List of symbols/abbreviations/acronyms/initialisms

AOE	Allowable Observer Error
C7	cervical 7^{th} vertebra
CAF	Canadian Armed Forces
CFAS	Canadian Forces Anthropometry Survey
df	degree of freedom
DND	Department of National Defence
Dr	driver
DRDC	Defence Research and Development Canada
DVA	driver visual aid
EPI	équipement de protection individuelle
FPV	fragmentation protective vest
IED	improvised explosive device
ISO	isometric
kg	kilogram
L	lumbar
L5	lumbar 5^{th} vertebra
LAV	light armoured vehicle
LORIT	LAV Operational Requirements Integration Task
mm	millimeter
n	number of participants in the group
NATO	North Atlantic Treaty Organisation
p	probability of statistical significance
PPE	personal protective equipment
PPEP	personal protective equipment with ballistic plates
Px	passenger
RTO	Research and Technology Organisation
S	sacral
S1	sacral 1^{st} vertebra
S3	sacral 3^{rd} vertebra
SPSS	Statistical Package for the Social Sciences

stdev	standard deviation
t	t-test statistic
T	Wilcoxon Signed Ranks test statistic
Th	thoracic
Tu	turret
U	Mann-Whitney test statistic
VBL	véhicule blindé léger
vs.	versus

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Military vehicles have the distinction of transporting fully kitted soldiers. The seated postures, and the influence of personal protective equipment (PPE) to soldier seated postures in light armoured vehicles (LAV) were not well understood. This study looked at the seated posture changes that occur when soldiers were wearing their PPE in three different LAV (LAV III, LAV 6 and LAV LORIT) while seated in three seats (passenger, driver and turret). A total of 23 male participants were monitored with inertial accelerometers to determine body posture angles while seated in LAV seats. Seated posture changes were evaluated with different levels of PPE, while seated in the three seats within the three LAV. Statistically significant differences were found between interactions involving PPE and vehicle seats. Participant seated postures were characterized showing differences between the different LAV seat designs. Footrest use effects on participant seated postures were evaluated with a participant subgroup (n = 12). Participant seated postures with footrest use resulted in lumbar kyphosis. The unsupported spinal curvature of another 30 participants were evaluated with a Valedo® Shape spinal mouse. Footrest use was re-evaluated with this tool, and showed a significant increase in lumbar kyphosis, and an increase in pelvic tilt extension.

Les véhicules militaires ont la particularité de transporter des soldats en tenue complète. Les postures assises et l'influence de l'équipement de protection individuelle (EPI) sur la posture assise des soldats dans un véhicule blindé léger (VBL) n'étaient pas bien comprises. La présente étude visait à examiner les changements observés dans la posture assise chez les soldats qui portent leur EPI dans trois différents VBL (VBL III, VBL 6 et VBL LORIT) selon leur position dans le véhicule (c'est-à-dire le siège du passager, le siège du conducteur et le siège de la tourelle). Au total, 23 participants de sexe masculin ont été suivis au moyen d'accéléromètres inertiels afin de déterminer les angles d'inclinaison de leur posture alors qu'ils étaient assis dans le VBL. Les changements observés dans la posture assise ont été évalués en fonction du port de différents niveaux d'EPI, et ce, pour chacun des trois sièges dans le VBL. Des différences statistiquement significatives ont été constatées quant aux interactions entre l'EPI et le siège occupé dans le véhicule. Les postures assises des participants ont été caractérisées selon les différences relatives à la conception des sièges de VBL. L'effet de l'utilisation d'un repose-pieds sur la posture assise des participants a été évalué auprès d'un sous-groupe de participants (n = 12). Chez les participants utilisant un repose-pieds, la posture assise a provoqué une cyphose lombaire. La courbure de la colonne vertébrale de 30 autres participants en position sans appui a été évaluée au moyen d'un dispositif Valedomd Shape Spinal Mouse. L'utilisation d'un repose-pieds a été réévaluée à l'aide de cet outil, ce qui a révélé une augmentation significative de la cyphose lombaire et une augmentation de l'inclinaison du bassin en extension.