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Spinal curvature while seated in light armoured vehicle (LAV) operational requirements integration task (LORIT) passenger seat mock-up

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IMPORTANT INFORMATIVE STATEMENTS

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

We wanted to know soldier spine curvature while seated in the light armoured vehicle (LAV) LAV operational requirements integration task (LORIT) passenger seat. Recent conflicts have highlighted discrepancies in the injury risk criteria for the lower back. To breach these discrepancies, a biofidelic instrumented spine is being developed. Soldier seated spine curvature will inform the development of the instrumented spine. Spine curvature was measured with a Valdeo Shape spinal mouse in a laboratory environment on a pseudo-LAV LORIT passenger seat. The test conditions compared the effects of personal protective equipment (PPE) and the use of a footrest on spinal curvature. We observed a cumulative effect on pelvic tilt and the lumbar spine when the footrest was used while wearing PPE. The spinal curvature findings will assist in the development of the biofidelic instrumented spine. The understanding that soldier posture in theatre will change according to their PPE and the use of a footrest should be considered when developing injury risk criteria, testing protocols, as well as survivability mechanisms.

Résumé

Nous souhaitions déterminer la courbure de la colonne vertébrale des soldats en position assise dans le siège du passager d'un véhicule blindé léger (VBL) de la Tâche d'intégration des exigences opérationnelles du VBL (LORIT). Lors de récents conflits, des lacunes ont été constatées relativement aux critères de risque de blessures touchant le bas du dos. Pour combler ces lacunes, une colonne vertébrale biofidèle instrumentée est en cours d'élaboration. La courbure de la colonne vertébrale des soldats en position assise orientera l'élaboration de la colonne vertébrale instrumentée. La courbure de la colonne vertébrale a été mesurée à l'aide d'un dispositif Valedo Shape Spinal Mouse sur un pseudo-siège de passager de VBL LORIT dans un environnement de laboratoire. Les conditions d'essai visaient à comparer les effets du port de l'équipement de protection individuelle (EPI) et de l'utilisation d'un repose-pieds sur la courbure de la colonne vertébrale. Nous avons observé un effet cumulatif sur l'inclinaison du bassin et la colonne lombaire lors de l'utilisation d'un repose-pieds en association avec le port de l'EPI. Les constatations relatives à courbure de la colonne vertébrale seront utiles pour la mise au point d'une colonne vertébrale biofidèle instrumentée. Il faudrait tenir compte du fait que la posture du soldat dans le théâtre sera différente selon le type d'EPI porté et l'utilisation d'un repose-pieds lors de l'élaboration des critères relatifs au risque de blessures, des protocoles d'essais ainsi que des mécanismes de surviabilité.

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Acknowledgements

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1 Introduction

This study was a follow up to a previous study to characterize the seated posture of soldiers in light armoured vehicles (LAV) (Chafé et al., in press). Chafé et al. assessed soldier seated body postures with wireless accelerometers while seated inside the vehicles. We wanted to determine seated spinal curvature in LAV seats with a Valedo™ Shape spinal mouse. The spinal mouse was designed to take measurements on the skin of the spinal column, and measures the angles between vertebrae, as well as calculates the spinal region angles of the thoracic and lumbar regions. A few research groups have previously evaluated this tool (Mannion et al., 2004; Guermazi, et al. 2006), and other research groups have used this tool in their studies (Muyor et al., 2011; Lopez-Minarro et al., 2012[a]; Lopez-Minarro et al, 2012[b]).

A universal seat was developed allowing access to the naked back through a centre slit in the backrest. The universal seat was completely adjustable and included an adjustable footrest. To evaluate the effects of personal protective equipment (PPE), a fragmentation vest with ballistic plates was cut out in the centre back to allow access to the bare skin of the spinal column.

Body posture angles were collected alongside the spinal curvature while seated in the universal seat to potentially infer a spinal curvature associated with the body posture angles collected within the LAV during the previous study. Body posture angles were collected with wireless inertial accelerometers. Similar techniques have previously been used by other research groups (Mork and Westgaard, 2009; Mörl and Bradl, 2013).

Soldier seated spinal curvature will inform the design and construction of an instrumented spinal surrogate that will be housed within an instrumented manikin to evaluate injury risks and injury prevention equipment. Realistic, and more importantly biofidelic injury risk criteria have the potential to decrease injuries to soldiers during conflict while in LAV.

Four conditions with and without PPE, and with and without the use of a footrest were evaluated during our study.

2 Methods

This study consisted of defining the spinal curvature of soldiers while seated in a pseudo-LAV LORIT passenger seat. The H-pt manikin was used to measure the angle dimensions of the LAV LORIT passenger seat and then adjust the universal seat to be the pseudo-LAV LORIT passenger seat. Accelerometers collected body segment angles alternately with the spinal mouse spine curvature measurements. Anthropometric measurements were collected to evaluate potential body dimension effects on the seated postures, and to determine which proportion of the Canadian Armed Forces (CAF) was represented anthropomorphically.

The step by step procedure followed during data collection is found in Annex A for future reference.

2.1 Universal seat

The universal seat was designed to be adjustable at the backrest, seat pan, footrest height and horizontal distance (Figure 1). To allow spinal mouse measurements on the skin of the back, the backrest had a 10 cm gap in the centre. Similarly, the seat pan rear had a 15 cm x 15 cm gap to allow access to the sacral vertebrae with the spinal mouse. The footrest bars were removed during the floor conditions.

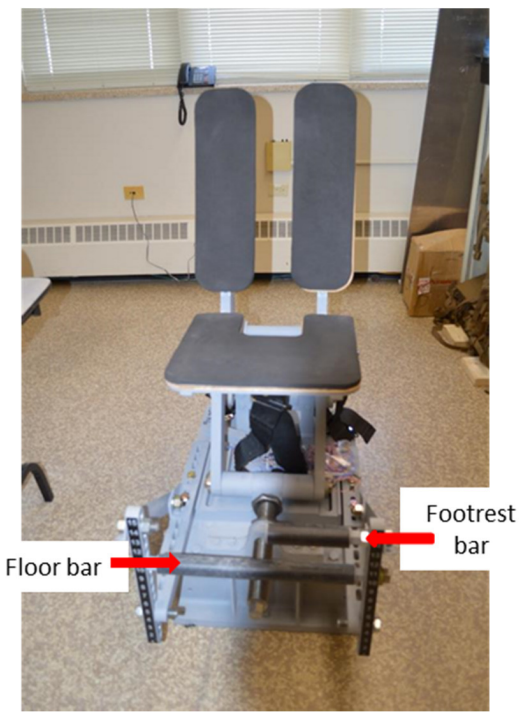

Figure 1: *Universal seat showing the backrest gap and the rear seat pan gap. The long lower bar represents the floor, and the shorter bar represents the footrest. Two short bars were used as the footrest during the study.*

2.1.1 Pseudo-LAV LORIT passenger seat

The LAV LORIT passenger seat dimensions were measured with a digital inclinometer and the H-point (H-pt) manikin. The universal seat was adjusted to the LAV LORIT passenger seat measurements with the digital inclinometer and the H-pt manikin into the pseudo-LAV LORIT passenger seat. The universal seat backrest was first set to 106°, and then the H-pt manikin was positioned in the universal seat (Figure 2). The universal seat was adjusted till the measurements of the H-pt manikin were equivalent to the LAV LORIT passenger seat measurements.

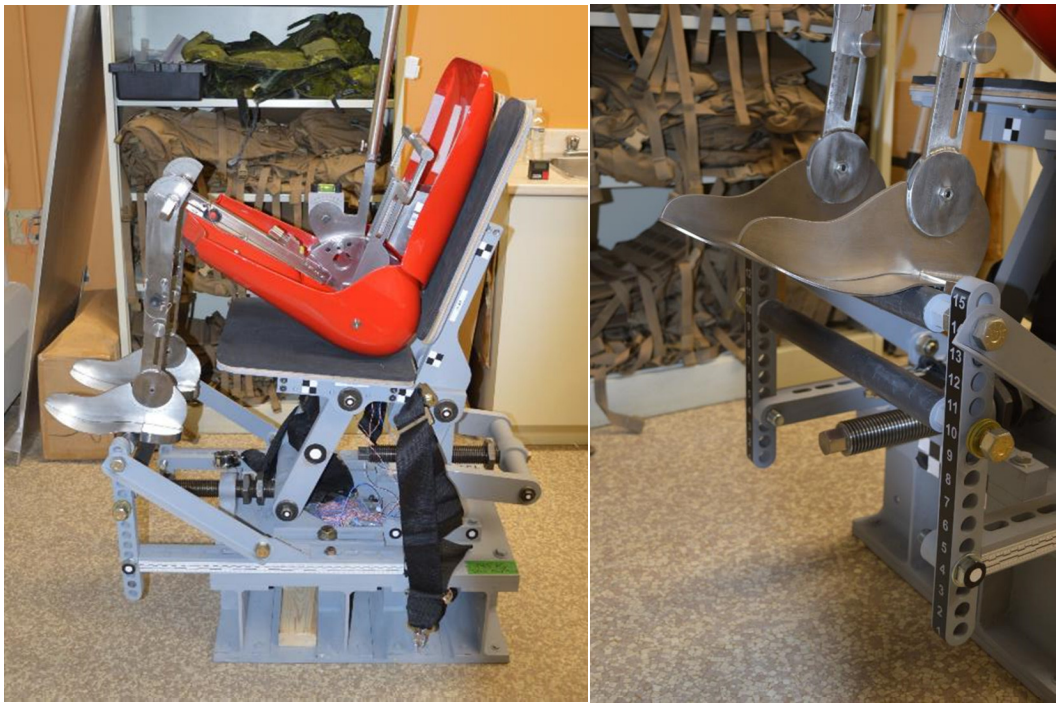

Figure 2: *The H-point manikin during adjustment of the universal seat to the pseudo-LAV LORIT passenger seat with feet on footrest.*

2.2 Specialized PPE

A standard fragmentation vest was cut along the centre back to allow access to the bare back with the spinal mouse. The rear ballistic plate had the centre 10 cm portion cut out and placed in the sliced rear pocket, with corresponding portions of the plate in each side. The centre of the vest and pockets were sewn to keep the cut plate portions in position (Figure 3). The fragmentation vest with both ballistic plates weighed 6.6 kg.

Figure 3: *The sliced fragmentation vest and rear ballistic plate portions. The left side of the rear pocket shown here with the ballistic plate portion inserted.*

The tactical vest was also sliced in the rear centre to allow for bare back measurements (Figure 4).

Figure 4: *The fully loaded tactical vest with the rear centre sliced open, red arrows indicating the cut lines.*

The fully loaded tactical vest weighed 8 kg during the study. Table 1 lists the equipment and weights contained in the tactical vest pockets.

Table 1: *Itemized contents and weight of fully loaded tactical vest.*

Item	Weight (kg)
Tactical vest (empty)	1.60
Tactical vest right side pockets:	
1 L canteen with shaped metal cup filled with water	1.40
medical kit, glow stick and Gerber multitool	0.25
2 filled ammunition magazine mock-ups	0.95
1 smoke grenade mock-up	0.25
Tactical vest left side pockets:	
Personal radio mock-up (15 cm x 16 cm x 5 cm) and field manual pouch	1.90
6 x AA batteries, 4 x 30 mL tubes sunscreen, headlamp mock-up, knife, fork and spoon ensemble	0.50
2 filled ammunition magazine mock-ups	0.95
1 smoke grenade mock-up	0.25
Total weight	8.05

When wearing the modified fragmentation vest and tactical vest, participant spinal columns were accessible while seated in the pseudo-LAV LORIT passenger seat (Figure 5).

Figure 5: *The modified PPE while seated in pseudo-LAV LORIT passenger seat gives access to the spinal column area.*

Study conditions with PPE required military participants to wear their issued combat helmet (CG634). Similarly, civilian participants wore a size medium CG634 helmet weighing 1.5 kg.

2.3 Study conditions

The study was designed to assess spinal curvature while seated in the pseudo-LAV LORIT passenger seat. The study also looked at the influence of a footrest, as well as PPE on seated spinal curvature. Four conditions were evaluated (Table 2). The conditions were in random order for each individual avoiding order effects during the study (Table B.1, Annex B). Participants were asked to stand between each triplicate measure of each condition to gather any potential differences when sitting multiple times.

Table 2: *The study conditions looking at the effects of footrest and PPE on seated spinal curvature.*

Condition	Footrest	PPE
A	No	No
B	Yes	No
C	No	Yes
D	Yes	Yes

2.4 Anthropometry

Ten semi-nude anthropometric measurements were collected for each participant (Table 3). Participants were asked to wear only undergarments, and socks. The procedures described in Keefe et al. (2015) were followed to identify most landmarks (Table 4), and take anthropometric measurements within the acceptable observer error. Two landmarks were identified following the procedure outlined in the Valedo®Shape user manual (2012). All landmarks were identified, and all measurements were taken by one observer.

Table 3: *Anthropometric measurements with acceptable observer error and measurement units.*

Anthropometric measurement	Acceptable observer error (AOE)	Unit
Weight	0.3	kg
Stature	10	mm
Acromial height	7	mm
Waist circumference	12	mm
Sitting height	6	mm
Acromial sitting height	9	mm
Popliteal height	7	mm
Seated knee height	2	mm
Seated buttock to knee length	6	mm
Seated buttock to popliteal length	7	mm

First, anthropometric landmarks were identified and marked with black eyeliner or a non-permanent marker as per participant preference.

Table 4: *Landmarks that were identified according to procedure references.*

Landmark	Procedure reference
Acromion	Keefe et al. (2015)
Cervicale	Keefe et al. (2015)
PSIS	Valedo Shape user manual (2012)
S3	Valedo Shape user manual (2012)
Omphalion	Keefe et al. (2015)
Suprapatella	Keefe et al. (2015)

Weight was measured with a Health o meter® Professional 349KLX (Pelstar, McCook, IL) weight scale. Standing posture measurements (i.e., stature and acromial height) were measured with a Gneupel Präzisions-Mechanik (GPM) anthropometer (GPM, Bachenbülach, Switzerland), and the waist circumference was measured with a Lufkin executive thin line 2 m measuring tape (Apex Tool Group, Sparks, MD). Participants were then asked to sit on an adjustable bench to collect the remaining anthropometric measurements (Figure 6). The seated posture measurements were collected with the GPM anthropometer.

Figure 6: *Adjustable bench used for anthropometric seated measurements and 90° reference posture.*

2.5 History of significant spinal pain

The study participants were asked to report their history of significant spinal pain (Annex C). Significant spinal pain was defined as "the presence of discomfort that intrudes into your awareness during your usual

activities, and has caused you to perform at a lower level, continue despite discomfort, or modify your activity to reduce the discomfort. It does not refer to trivial mild aches that are easily dismissed and have no functional significance." Participants reported on significant pain experienced within the last 12 months, as well as prior to the last 12 months (while excluding the last 12 months).

2.6 Spinal curvature

2.6.1 Valedo™ Shape spinal mouse

The Valedo® Shape spinal mouse (Hocoma, Volketswil, Switzerland) was used in this study to measure seated spine curvature in the sagittal plane. The spinal mouse consisted of two wheels that were rolled along the spine from the C7 cervical vertebra all the way down to the S3 sacral vertebra (Figure 7). Standing spinal curvature reference measurements were collected with participants in their normal standing posture, their full torso flexion and their full torso extension.

Figure 7: *Spinal mouse measurement on participant in neutral seated posture. Photos taken by Capt Tommy Poirier.*

The spinal mouse software (Valedo Motion v2, Hocoma AG, Volketswil, Switzerland) generated sagittal plane segmental angles (between each vertebrae), regional angles (thoracic and lumbar regions), pelvic tilt (sagittal pelvic tilt angle in relation to the vertical reference 0°), vertical inclination (angle of direct connection line from S1 to C7 in relation to the vertical reference 0°), and spine length. 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 8.

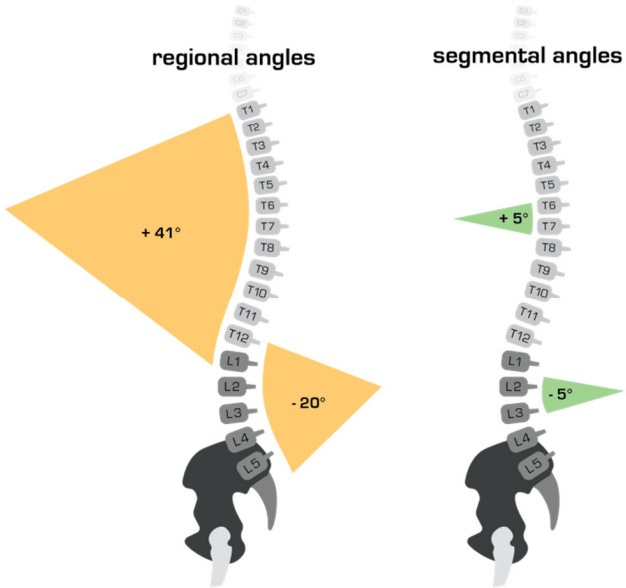

Figure 8: *Positive angles indicate kyphosis, and negative angles indicate lordosis. Graphics design by Sarah Tierney.*

Pelvic tilt and vertical inclination were positive values towards flexion and negative values towards extension as relative to the true vertical axis (0°).

2.6.2 Seated 90° reference posture

Participants were seated on a backless bench, the knee joint positioned at 90° and confirmed with an analog Lafayette Gollehon extendable goniometer (Lafayette Instrument Company, Lafayette, IN). The spinal mouse was used to measure the vertical inclination between the S1 and C7 to position the participants as close to 90° (i.e., 0° in the Valedo Motion v2 software) as possible.

Figure 9: *Rendering of the seated 90° reference posture. Graphics design by Capt Tommy Poirier.*

2.6.3 Seated spinal curvature

Participants' spine curvature was measured while seated in the pseudo-LAV LORIT passenger seat in triplicate with 20 participants. All spinal mouse measurements were collected by one examiner. The participants were asked to stand between the triplicate measurements of a single condition. Each individual's triplicate measurements were averaged. The individual averages were then grouped together, and the group mean and standard deviation (stdev) (n = 20) were reported for each condition (Figure 10).

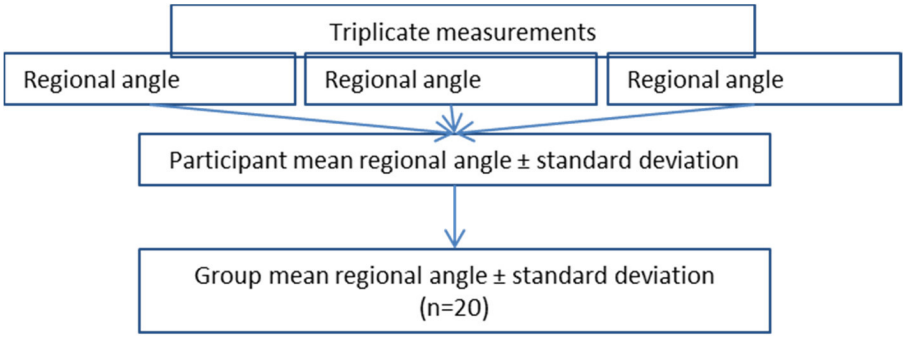

Figure 10: *Spinal mouse mean angle calculation scheme of the group mean ± standard deviation.*

2.6.4 Angle differences between standing and seated postures

The difference between standing and seated posture spinal region angles and vertebrae segment angles was calculated for each participant. The participant differences were then grouped to calculate the mean and stdev of differences.

2.7 Delsys® Trigno wireless system

The Delsys® Trigno wireless system sensor consists of electromyography electrodes and inertial accelerometers (Delsys Inc., Natick, MA) (Figure 11). This system was used to determine body segment angles while seated in the pseudo-LAV LORIT passenger seat. These accelerometers were used to follow-up with a previous study with the intent to potentially extrapolate spinal curvature from this assessment to the previous assessment done directly in LAV seats (Chafé et al., in press).

Figure 11: *Delsys® Trigno wireless system and Trigno sensor showing the arrow direction.*

2.7.1 Accelerometer placement

The five accelerometers were affixed to participants with 2.5 cm wide Atoma clear first aid tape (McKesson Canada Corporation, Montreal, Qc), placed as follows:

1. C7 accelerometer—6 cm to the right of the Cervical 7th vertebra (C7) with the Trigno sensor arrow pointing up.
2. L5 accelerometer—On the right posterior superior iliac spine (PSIS) equivalent to the Lumbar 5th vertebra (L5) area with the Trigno sensor arrow pointing up.
3. Thigh accelerometer—Measured from the buttock edge to half the seated buttock to popliteal length, and made a vertical mark with black eyeliner or a non-permanent marker as per participant preference. Then at that mark, the observer measured the thigh clearance with a GPM sliding caliper (GPM, Bachenbülach, Switzerland), and created a horizontal mark to form a cross at half the thigh clearance to position the accelerometer at the mid outer side of the right thigh. The accelerometer was positioned with the participant seated, and the Trigno sensor arrow pointing up towards the top of the thigh.
4. Calf accelerometer—Measured from the popliteal to 0.75 of the popliteal height and made a horizontal mark on the outer side of the right calf with the eyeliner or marker. Then at that mark, measured the calf width with a GPM sliding caliper, and created a vertical mark forming a cross at half the calf width to position the accelerometer at the mid outer side of the right calf. The Trigno sensor arrow was pointing up towards the knee.
5. Boot accelerometer—The last accelerometer was positioned on the toe portion of the right boot, with the Trigno sensor arrow pointing inwards towards the right ankle.

Figure 12 shows the accelerometers placed on the body.

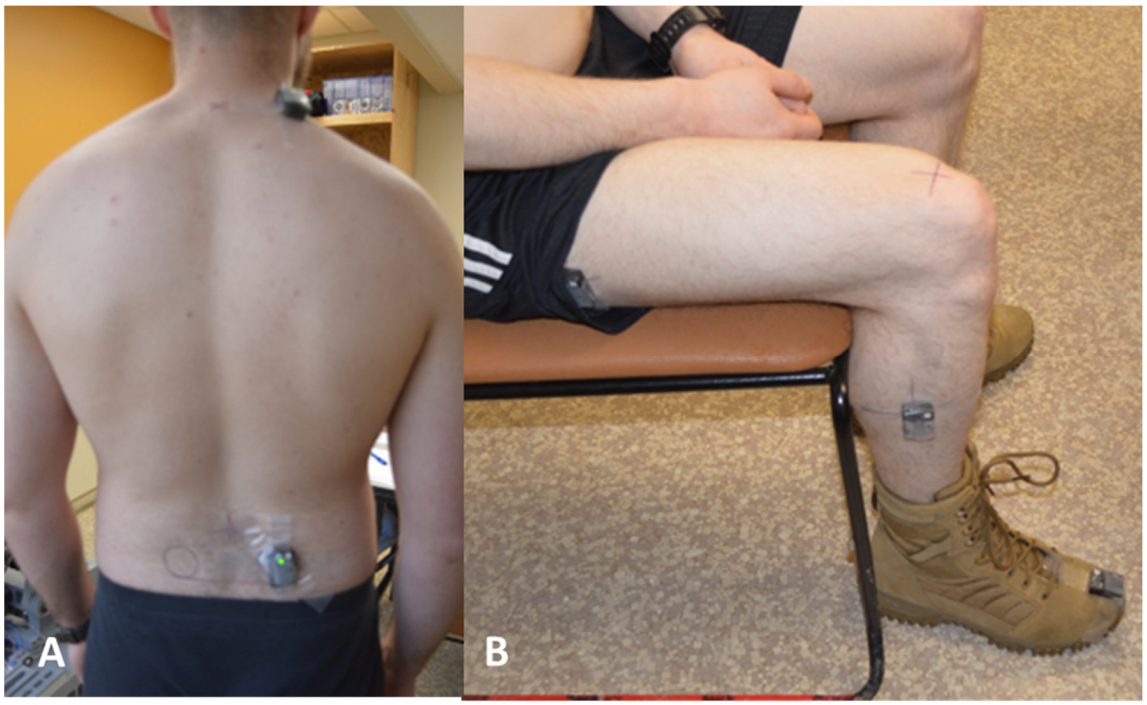

Figure 12: *Accelerometer placement in A) C7 vertebra area (top accelerometer) and L5 vertebra area (lower accelerometer), and B) right thigh, right mid-calf and top of right boot.*

2.7.2 Angle output

Only the accelerometer function of the sensor was activated at a frequency of 150Hz during data collection. Body segment angles were collected for 15 seconds and in triplicate for each condition (see Section 2.3, Table 2). The 15 second mean angle was calculated for each individual measurement. The relative mean angle was calculated as the difference from the 90° seated reference posture (see Section 2.6.2). The three relative mean angles were averaged to give the participant relative mean angle ± stdev of the triplicate. The participant relative mean angles were grouped for the 20 participants, and the group relative mean angles were reported with their respective stdev (Figure 13).

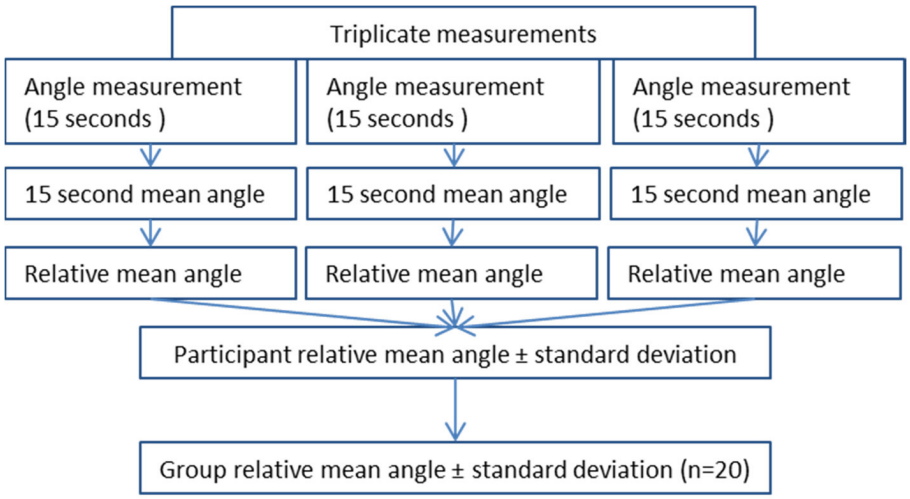

Figure 13: *Group relative mean angle calculation scheme.*

Relative mean angles from the C7 and L5 accelerometers indicated a torso flexion when angle <90° or a torso extension when angle >90°. The thigh accelerometer indicated a hip flexion when angle >0° from the horizontal axis or a hip extension when angle <0° below the horizontal axis. The calf accelerometer indicated a knee flexion when angle <0° from the vertical axis or a knee extension when angle >0° from the vertical axis. The boot accelerometer indicated an ankle flexion when angle >0° from the horizontal axis, or an ankle extension when angle <0° from the horizontal axis.

2.8 Statistical analysis

The group mean age and standard deviation were calculated with the category average (e.g., category 16–20 years = 18 years). The participant anthropometry data was compared to the 2012 Canadian Forces Anthropometry Survey (Keefe et al., 2015), and the corresponding percentiles were reported for the minimum, maximum and mean group values.

Anthropometry relationships with the body posture angles were evaluated with the Pearson's product-moment correlation coefficient (r). Presented results followed the standard format $r(20) = 0.687$, $p = 0.001$, where the number of data points is in brackets (i.e., 20), followed by the r coefficient, and the statistical probability (p) (Coolican, 2009[a]).

The group body segment mean angles of the different conditions were evaluated for skewness and kurtosis to determine the use of a parametric (normal distribution) or non-parametric statistical tests. If the skewness or kurtosis statistic was twice that of its standard error, data was evaluated with a non-parametric test. The group body segment mean angles were compared between the four study conditions with the parametric paired t-test (t) or the non-parametric Wilcoxon signed ranks test (T) (Coolican, 2009[b]). Paired t-test results were presented in the standard format: $t(19) = -4.68$, $p < 0.001$, where 19 represents the degrees of freedom between the 20 participants, -4.68 was the paired t-test statistic, followed by the statistical significance probability (p). The Wilcoxon test results were presented in the standard format: $T = 42.00$, $p = 0.019$, where T was the lowest value between the ranks total, and the statistical significance probability (p). The relationships between body segment angles and spinal region angles were evaluated with the Pearson's product-moment correlation coefficient (r).

Statistical significance was set at $p \leq 0.010$ to reduce the chance of getting Type I and Type II probability errors for all tests.

3 Results

The participants' characteristics are presented relative to the group, followed by the group mean spinal curvature, and mean seated body posture angles. One participant demonstrated a different seated posture compared to the rest of the group. This participant's posture was presented to visually show the different influences of the footrest and PPE that were observed.

During the PPE study conditions, military participants wore their issued combat helmet (CG634), while civilian members wore a medium sized CG634 combat helmet. The group mean helmet weight was 1.6 kg ± 0.1 kg (n = 20), helmet weights ranged from 1.5 kg to 1.8 kg. The PPE overall mean weight on participants was 16.2 kg (see Section 2.2, and Table 1 for specific itemized weight of the loaded tactical vest and fragmentation vest).

Statistically significant comparisons ($p \leq 0.010$) between the four conditions highlighted the differences in body posture and spinal curvature resulting from the addition of the footrest and the PPE. Then we presented the statistically significant relationships ($p \leq 0.010$) found between the body posture angles, spinal curvature, and anthropometry measurements.

3.1 Participant characteristics

The study participants consisted of 17 military members from the 2nd Canadian Division Support Base Valcartier, and 3 civilians from the Defence Research and Development Canada (DRDC) – Valcartier Research Centre. Seventeen participants were male (85%), along with 3 females (15%). This ratio was comparable to the 2012 Canadian Forces Anthropometry Survey (CFAS), where 14% of participants were female (Keefe et al., 2015), and the reported 16% female representation within the Canadian Armed Forces (CAF) in February 2019 (National Defence and the Canadian Armed Forces Backgrounder, 2019). The participant group mean age was 30±10 years (Figure 14), comparable to the 2012 CFAS that reported 31±9 years.

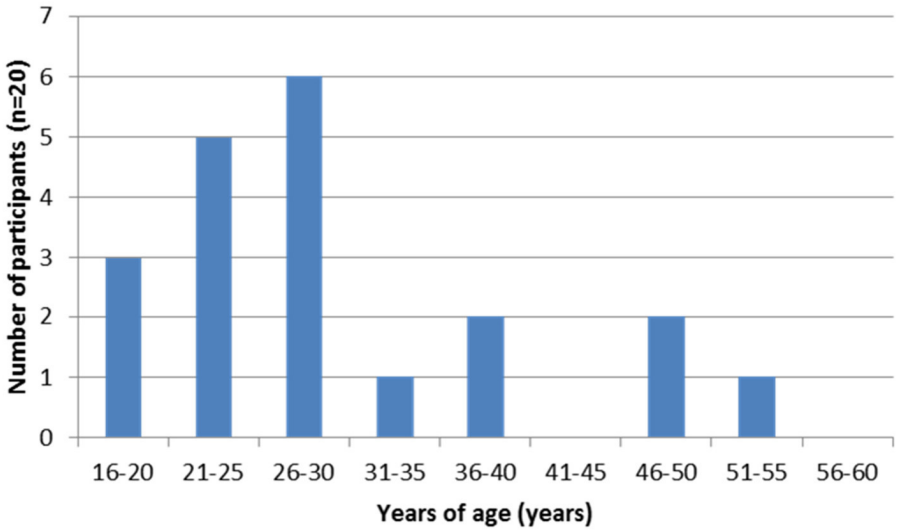

Figure 14: *Distribution of participants according to age (n = 20).*

3.1.1 Anthropometry

The study participants' anthropometry measurements were compared to the 2012 CFAS and we determined the equivalent percentiles of the minimum, maximum and mean values (Table 5). Overall, the study participants ranged from 1% to 98% among the measurements that were assessed. The study group mean values ranged from 41% to 71% of the CFAS group.

Table 5: *Study participants' group anthropometric measurements (n = 20) and the CFAS equivalent percentiles (n = 2195).*

Anthropometry measurement	Participant measurements			CFAS equivalent percentiles		
	Minimum	Maximum	Mean ± stdev	Minimum	Maximum	Mean
Weight (kg)	57.7	113.3	83.0±15.9	3%	95%	48%
Stature (mm) [a]	1611	1857	1755±69	5%	92%	52%
Acromial height (mm) [a]	1314	1537	1445±63	5%	93%	57%
Waist circumference—omphalion (mm)	708	1163	907±122	1%	94%	41%
Sitting height (mm)	847	976	923±34	3%	93%	51%
Acromial height sitting (mm)	542	670	611±30	2%	98%	57%
Popliteal height (mm) [a]	397	468	434±21	22%	97%	71%
Knee height, sitting (mm)[a]	492	587	545±29	1%	97%	66%
Buttock-knee length (mm)[b]	533	657	606±31	1%	94%	50%
Buttock-popliteal length (mm)	417	538	495±30	1%	97%	63%

a These measurements were taken with socks in our study contrary to the CFAS procedures.

b The buttock-knee length had an n = 18.

3.1.2 History of spinal pain

Spinal pain history was collected to ensure participants would not be injured during the data collection. When a participant reported a history of spinal pain, they were counselled that data collection could stop or pause at any moment. Participant responses were tabulated in Table 6.

Table 6: *Number of participants reporting spinal significant pain history.*

Spinal area	Significant pain history (n = 20)			
	Last 12 months		Prior to last 12 months	
	Yes	No	Yes	No
Neck	3	17	4	16
Shoulder(s)	2	18	5	15
Upper back	1	19	3	17
Mid back	3	17	3	17
Lower back	8	12	6	14
Neck pain radiating down the arms	1	19	1	19
Low back pain radiating down the legs	3	17	4	16

In general, up to 40% of participants reported significant lower back pain in the last 12 months, and up to 30% reported significant lower back pain prior to the last 12 months. None of the participants complained of significant pain during the experiment, nor did they ask for breaks or pauses.

3.1.3 Participant reactions

Approximately 10% of participants made comments that referred to the pseudo-LAV LORIT passenger seat being unnatural due to the seat pan and backrest gaps required for the spinal mouse data collection. Approximately 25% of participants commented that the accelerometer placed at L5 was awkward or would shift their seated posture to reduce the pressure the accelerometer created on the lower back when against the backrest.

3.2 Spinal curvature

Spinal curvature was measured with the Valedo® Shape spinal mouse and we reported the spine regional angles and vertebrae segment angles for standing and seated postures.

3.2.1 Standing spinal curvature

The group standing reference mean spine curvature angles were reported with their stdev (Figure 15).

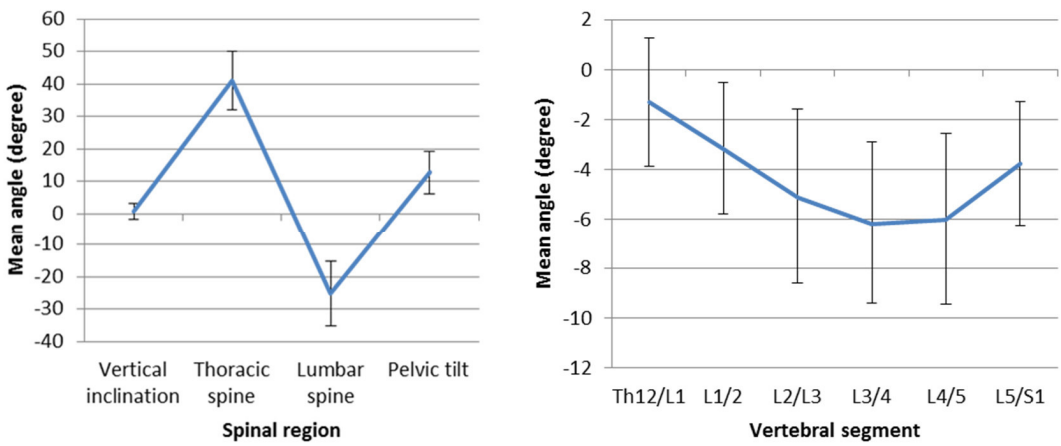

Figure 15: *The group's standing reference spine region and vertebral segment mean angles with their associated stdev (n = 20).*

The difference between the standing posture angles and the seated Condition A (no footrest, no PPE) angles were calculated for each participant. Those individual differences were averaged for the group (n = 20) and listed in Table 7 with the respective stdev.

Table 7: *Mean of the differences between the standing spinal curvature angles and Condition A (no footrest, no PPE) seated spinal curvature angles with their respective stdev (n = 20).*

Spinal regions and vertebral segments	Mean difference ± stdev (n = 20)
Pelvic tilt	35°±7°
Lumbar spine	-27°±10°
Vertical inclination	11°±8°
L3/L4	-7°±3°
L4/L5	-7°±4°
L2/L3	-5°±3°
L5/S1	-4°±3°
L1/L2	-3°±2°
Th12/L1	-1°±3°
Thoracic spine	0°±6°

The three angles that manifested the largest differences from the standing to the seated posture were the pelvic tilt, the lumbar spine, and the vertical inclination, respectively.

3.2.2 Seated spinal curvature

Seated spinal curvature was measured in four study conditions combining the use of a footrest and PPE (see Section 2.3, Table 2). Figure 16 shows the group mean spinal region angles in each condition with the respective stdev. The statistical significance set at $p \leq 0.010$ was indicated on the figure with an asterisk (*). Table D.1 in Annex D lists the mean angles and their stdev.

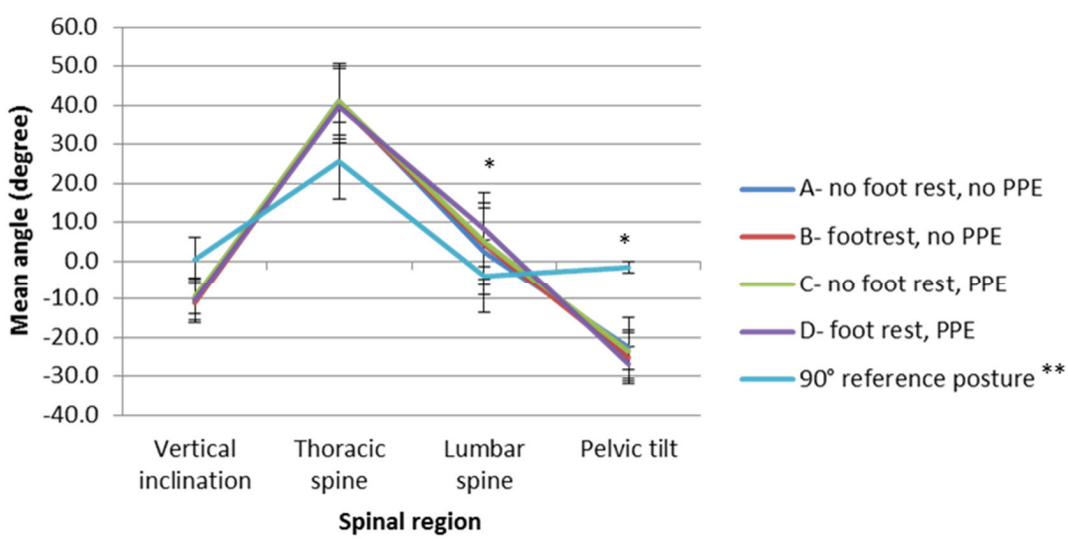

Figure 16: *Seated group mean spinal region angles with stdev (n = 20).* Indicating statistical significance $p \leq 0.010$; **90° seated reference posture was n = 19.*

The group mean vertical inclination while seated in the 90° reference posture was 0.3°±1.3° (n = 19) (Figure 16). This value confirmed the reference torso angle posture during data collection just prior to collecting accelerometer measurements. The accelerometer readings of the 90° reference posture were used as the reference to calculate participant relative angles in the different conditions (see Section 2.7.2, Figure 13).

Figure 17 shows the group vertebral segment mean angles with the respective stdev. The statistical significance ($p \leq 0.010$) was indicated in the figure with an asterisk (*).Table D.2 in Annex D lists the mean angles and their stdev.

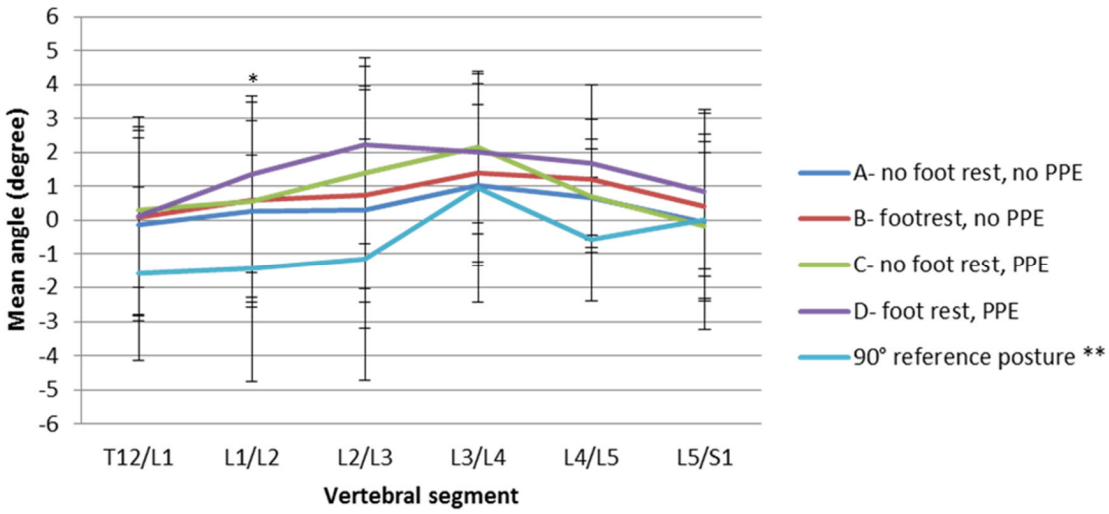

Figure 17: *Group mean vertebral segment angles with stdev (n = 20). * Indicating statistical significance p≤0.010; **90° seated reference posture was n = 19.*

The four conditions were compared to each other with the paired t-test (parametric) or the Wilcoxon signed ranks test (non-parametric) as described in Section 2.8—Statistical analysis. The statistical significance was set at $p \leq 0.010$. The group pelvic tilt mean regional angles had significant differences between Condition comparisons A versus B, A versus D, B versus D, and C versus D (Table 8). The group lumbar spine mean regional angles had significant differences between Condition comparisons A versus D, and B versus D. The group vertebral segment L1/L2 mean angles had significant differences between Condition comparisons A versus D, and C versus D.

Table 8: *List of the spinal regions and vertebral segments that reached statistically significant differences ($p \leq 0.010$) between the condition comparisons with the paired t-test or Wilcoxon signed ranks test.*

Condition comparison	Spinal regions	Vertebral segments
A versus B	Pelvic tilt	
A versus C		
A versus D	Pelvic tilt, Lumbar spine	L1L2
B versus C		
B versus D	Pelvic tilt, Lumbar spine	
C versus D	Pelvic tilt	L1L2

One participant presented a lean forward seated posture that was different from all other participants (Figure 18).

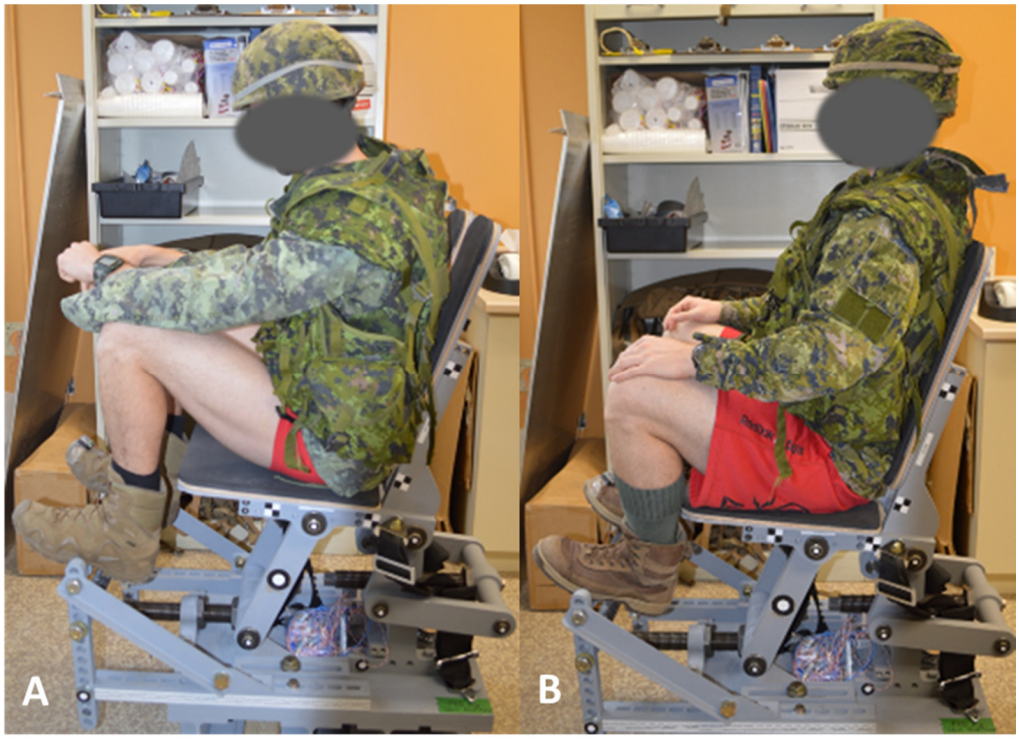

Figure 18: *Unique participant who used a forward torso seated posture (A) compared to all other study participants (B).*

Figure 19 shows that the forward posture increased the vertical inclination ranging between 6° and 23° where the group mean vertical inclination was -10° (see Figure 16). The lumbar spine angle was increased ranging between 27° and 36° for the different conditions where the group mean lumbar angle ranged between 1° and 10° (see Figure 16).

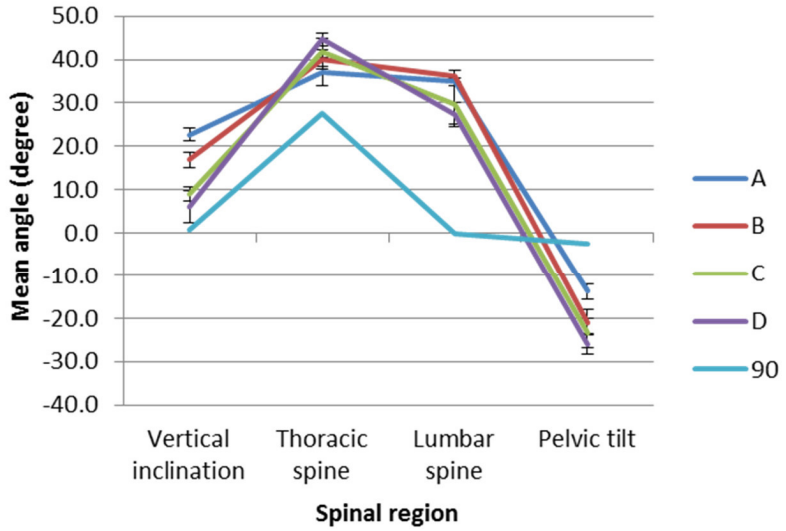

Figure 19: *Unique participant spinal region mean angles with stdev (n = 3) who used a forward torso seated posture.*

The unique participant vertebral segment angles in the lumbar area had a different pattern compared to the group pattern (Figure 20).

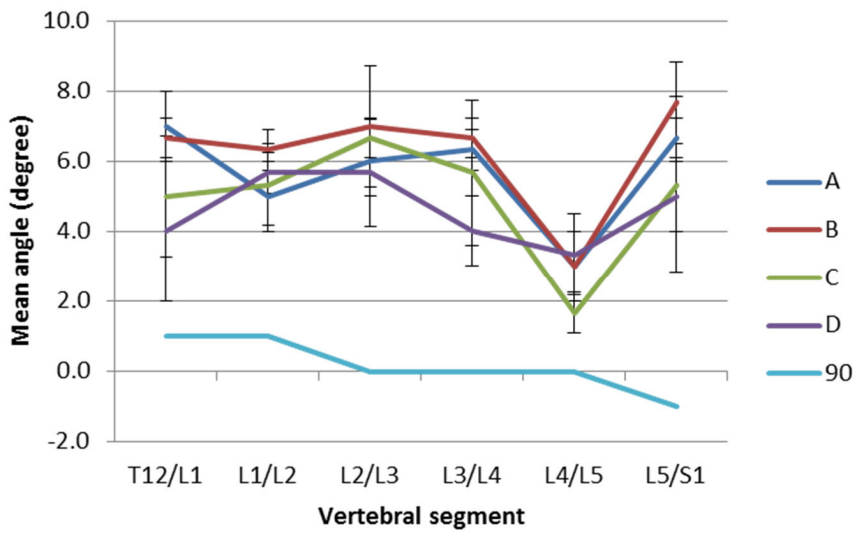

Figure 20: *Unique participant vertebral segment mean angles with stdev (n = 3) who used a forward torso seated posture.*

The unique participant T12/L1 vertebral segment ranged between 4° and 7° where the group mean T12/L1 was close to 0° (see Figure 17). The group vertebral segment mean angles varied between 0° and 2° (see Figure 17), where the unique participant forward posture created vertebral segment angles ranging around 2° to 8°.

3.3 Seated body posture angles

Figure 21 shows the mean relative body segment angles with their respective stdev of the four study conditions. The paired t-test (parametric) compared the different conditions as described in Section 2.8—Statistical analysis. These tests revealed statistically significant differences ($p \leq 0.010$) between conditions, these are indicated with an asterisk (*). Table D.3 in Annex D lists the mean angles and their stdev.

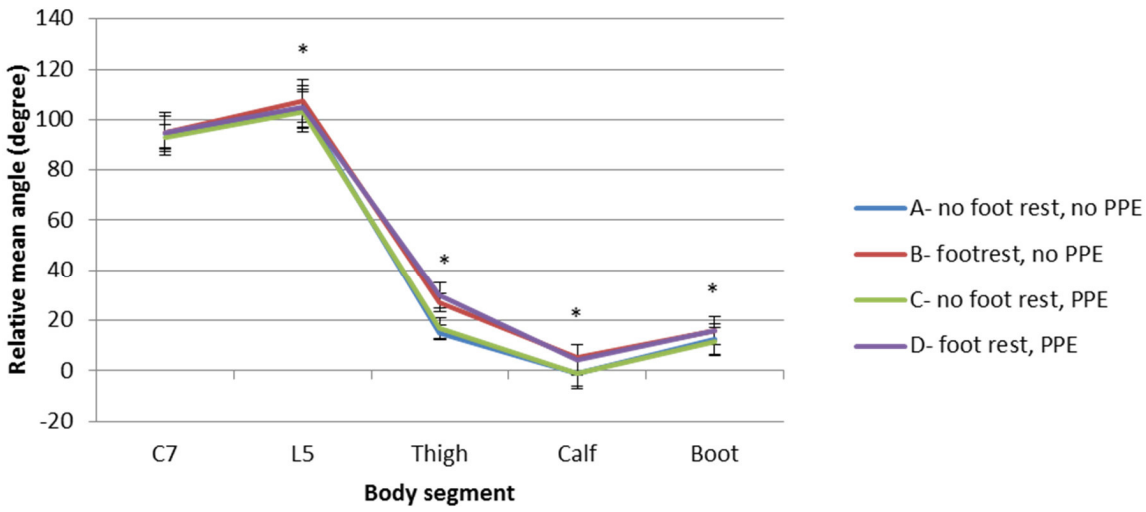

Figure 21: *Group mean body segment relative angles with stdev (n = 20).* indicates $p \leq 0.010$ statistical significance.*

The paired t-test determined statistically significant differences amongst the body posture angles between the different conditions (Table 9).

Table 9: *Paired t-test statistically significant comparisons ($p \leq 0.010$).*

Condition comparison	Body posture angles
A versus B	L5, Thigh, Calf, Boot
A versus C	Thigh
A versus D	Thigh, Calf, Boot
B versus C	Thigh, Calf, Boot
B versus D	Thigh
C versus D	Thigh, Calf, Boot

A unique participant used a very different seating posture than the other participants (see Figure 18). This individual leaned forward with wrists on their knees, resulting in a torso flexion with C7 angles ranging between 60° and 80° (Figure 22), compared to the group mean C7 angles which ranged between 93° and 95° (see Figure 21). The unique participant L5 relative mean angles were <100° (Figure 22), however the group L5 mean angles ranged between 103° and 107° (see Figure 21).

The effect of adding PPE (Conditions A to C and B to D) changed this individual's torso flexion by 15° (A to C—no footrest), and 10° (B to D—with footrest) (Figure 22), where the group mean differences of the torso (C7 angles) were 1° and 0°, respectively between these conditions (see Figure 21). The unique participant experienced a difference of 14° and 10° at the C7 body segment, without and with footrest respectively, compared to the group.

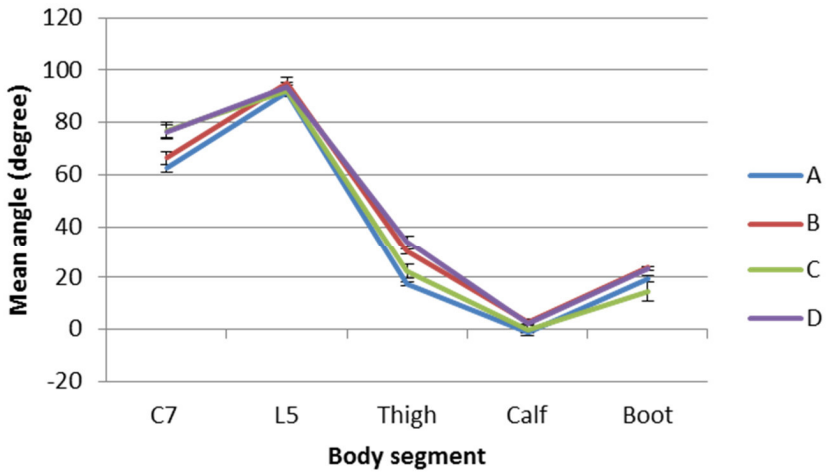

Figure 22: *Unique participant mean relative angles ± stdev (n = 3) who used a lean forward posture.*

The unique forward leaning posture influenced the L5 body segment relative angles. These ranged between 92° and 95° (Figure 22) compared to the group L5 mean relative angles that ranged between 103° to 107° (see Figure 21). Differences ranging from 11° to 13° between the unique participant and the group, however there does not seem to be a PPE specific effect between Conditions A to C and B to D as was observed with the C7 body segment.

3.4 Condition comparisons

Condition comparison results were presented only when statistical significance $p \leq 0.010$ was observed either with parametric or non-parametric tests as described in Section 2.8—Statistical analysis and Tables 8 and 9.

3.4.1 Condition A versus B

Condition A to B moved the feet from the floor to the footrest. The group mean pelvic tilt angle while seated in Condition A (-23°±6°) then B (-25°±5°) increased pelvic extension by 2° (Paired t-test, $t(19) = 3.64$, $p = 0.002$).

The group L5 mean angle while seated in Condition A (105°±7°) then B (107°±8°) increased torso extension by 2° ($t(19) = -2.95$, $p = 0.008$). The group thigh mean angle while seated in Condition A (15°±3°) then B (27°±4°) increased hip flexion by 12° ($t(19) = -29.99$, $p < 0.001$). The group calf mean angle while seated in Condition A (-1°±6°) then B (5°±5°) increased knee extension by 6° ($t(19) = -12.03$, $p < 0.001$). The group boot mean angle while seated in condition A (12°±6°) then B (16°±5°) increased ankle flexion by 4° ($t(19) = -4.68$, $p < 0.001$).

3.4.2 Condition A versus C

Condition A to C saw the addition of PPE. The group thigh mean angle while seated in condition A (15°±3°) then C (17°±4°) increased hip flexion by 2° (t(19) = -3.53, p = 0.002).

3.4.3 Condition A versus D

Condition A to D moved the feet from the floor onto the footrest and the addition of PPE. The group pelvic tilt mean angle while seated in Condition A (-23°±6°) then D (-27°±5°) increased pelvic extension by 4° ($t(19) = 5.28$, $p < 0.001$). The group lumbar spine angle while seated in Condition A (2°±11°) then D (8°±9°) increased lumbar kyphosis by 6° (Wilcoxon signed ranks test, $T = 16.00$, $p = 0.001$). The group vertebral segment L1/L2 mean angle while seated in condition A (0°±3°) then D (1°±3°) increased L1/L2 kyphosis by 1° ($t(19) = -3.36$, $p = 0.003$).

The group thigh mean angle while seated in Condition A (15°±3°) then D (30°±5°) increased hip flexion by 15° ($t(19) = -22.42$, $p < 0.001$). The group calf mean angle while seated in Condition A (-1°±6°) then D (4°±6°) increased knee extension by 5° ($t(19) = -10.09$, $p < 0.001$). The group boot mean angle while seated in Condition A (12°±6°) then D (16°±6°) increased ankle flexion by 4° ($t(19) = -6.28$, $p < 0.001$).

3.4.4 Condition B versus C

Condition B to C moved the feet from the footrest onto the floor, and the addition of PPE. The group thigh mean angle while seated in Condition B (27°±4°) then C (17°±4°) decreased hip flexion by 10° (t(19) = 21.54, p < 0.001). The group calf mean angle while seated in Condition B (5°±5°) then C (-1°±5°) decreased knee flexion by 6° (t(19) = 5.42, p < 0.001). The group boot mean angle while seated in Condition B (16°±5°) then C (12°±5°) decreased ankle flexion by 4° (t(19) = 5.44, p < 0.001).

3.4.5 Condition B versus D

Condition B to D added PPE, feet were placed on the footrest for both conditions. The group pelvic tilt mean angle while seated in Condition B (-25°±5°) then D (-27°±5°) increased pelvic extension by 2° (t(19) = 3.35, p = 0.003). The group lumbar spine angle while seated in Condition B (4°±11°) then D (8°±9°) increased lumbar kyphosis by 4° (Wilcoxon signed ranks test, T = 34.00, p = 0.008).

The group thigh mean angle while seated in Condition B (27°±4°) then D (30°±5°) increased hip flexion by 3° (t(19) = -5.38, p < 0.001).

3.4.6 Condition C versus D

Condition C to D moved the feet from the floor to the footrest while wearing PPE in both conditions. The group pelvic tilt mean angle while seated in Condition C (-23°±5°) then D (-27°±5°) increased pelvic extension by 4° (t(19) = 3.13, p = 0.005). The group vertebral segment L1/L2 mean angle while seated in Condition C (0°±3°) then D (1°±3°) resulted in a 1° kyphosis (t(19) = -3.08, p = 0.006).

The group thigh mean angle while seated in Condition C (17°±4°) then D (30°±5°) increased hip flexion by 13° (t(19) = -20.52, p < 0.001). The group calf mean angle while seated in Condition C (-1°±5°) then D (4°±6°) increased knee flexion by 5° (t(19) = -4.76, p < 0.001). The group boot mean angle while seated in Condition C (12°±5°) then D (16°±6°) increased ankle flexion by 4° (t(19) = -7.46, p < 0.001).

3.5 Statistically significant relationships

The Pearson's product-moment correlation coefficient (r) revealed statistically significant relationships ($p \leq 0.010$) between the body posture and spinal curvature angles among the four conditions. Statistically significant relationships were also observed between the anthropometry measurements and the Condition A seated posture.

3.5.1 Body posture and spinal curvature relationships

The Pearson's product-moment correlation coefficient (r) determined that there were statistically significant ($p \leq 0.010$) relationships between the accelerometer body posture angles and the spinal curvature angles while seated in the different conditions (Table 10). The vertical inclination calculation included the C7 (see Section 2.6.1, i.e., angle of direct connection line from S1 to C7 in relation to the vertical reference 0°), therefore this finding was to be expected.

Table 10: *Statistically significant relationships ($p \leq 0.010$) between seated body posture angles and seated spinal curvature angles ($n = 20$).*

Condition	Accelerometer body angle	Spinal curvature angle	Pearson's product-moment correlation coefficient (*r*)
A	C7 body angle	Seated lumbar spine angle	$r(20) = -0.689$, $p = 0.001$
	C7 body angle	Vertical inclination	$r(20) = -0.925$, $p < 0.001$
	L5 body angle	Pelvic tilt	$r(20) = -0.687$, $p = 0.001$
B	C7 body angle	Seated lumbar spine angle	$r(20) = -0.631$, $p = 0.003$
	C7 body angle	Vertical inclination	$r(20) = -0.923$, $p < 0.001$
	L5 body angle	Pelvic tilt	$r(20) = -0.651$, $p = 0.002$
C	C7 body angle	Seated lumbar spine angle	$r(20) = -0.606$, $p = 0.005$
	C7 body angle	Vertical inclination	$r(20) = -0.866$, $p < 0.001$
	L5 body angle	Pelvic tilt	$r(20) = -0.418$, $p = 0.067$[a]
D	C7 body angle	Seated lumbar spine angle	$r(20) = -0.458$, $p = 0.042$[a]
	C7 body angle	Vertical inclination	$r(20) = -0.839$, $p < 0.001$
	L5 body angle	Pelvic tilt	$r(20) = -0.660$, $p = 0.002$

[a] These results were not statistically significant.

Figure 23 shows the C7 mean body angle and the seated lumbar spine angle moderate relationship with Conditions A (blue diamonds), B (red squares) and C (green triangles), however not with Condition D (purple crosses). The three conditions showed a similar relationship moving from torso flexion (<90°) to torso extension (>90°) reflecting a shift of lumbar spine kyphosis (>0°) through neutral to lumbar lordosis (<0°).

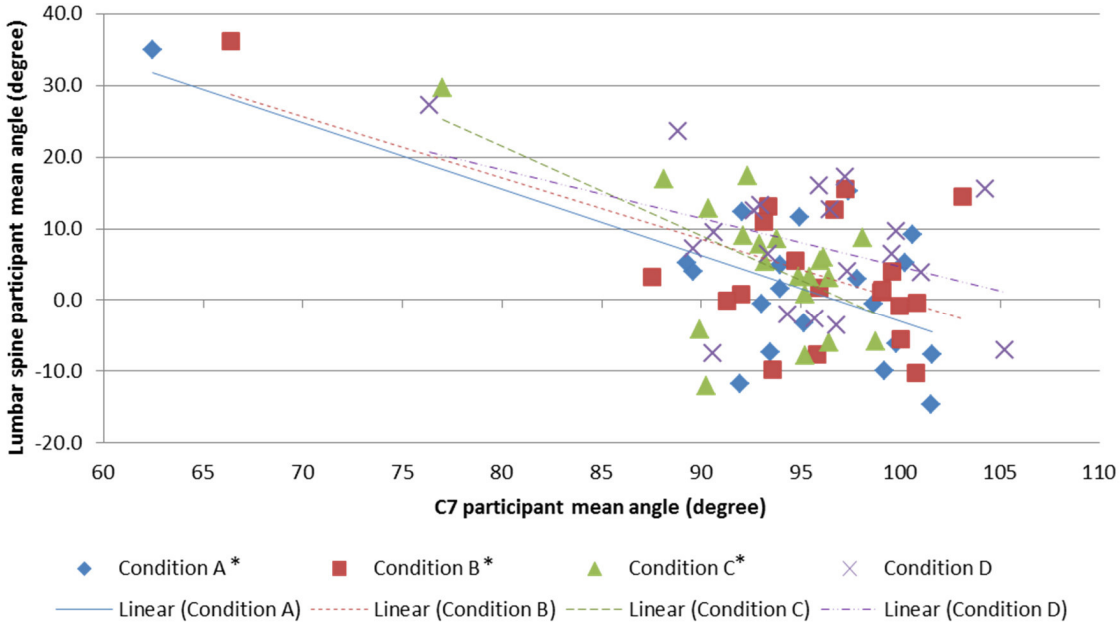

Figure 23: *Relationship between seated participant C7 and lumbar spine mean angles for the four study conditions (n = 20).*statistically significant p ≤ 0.010.*

Similarly, the L5 mean body angle and the pelvic tilt showed a moderate relationship with Conditions A (blue diamonds), B (red squares) and D (purple crosses), however not with Condition C (green triangles). The three conditions showed a similar relationship where increased torso extension (>90°) reflected an increased pelvic extension (<0°) (Figure 24).

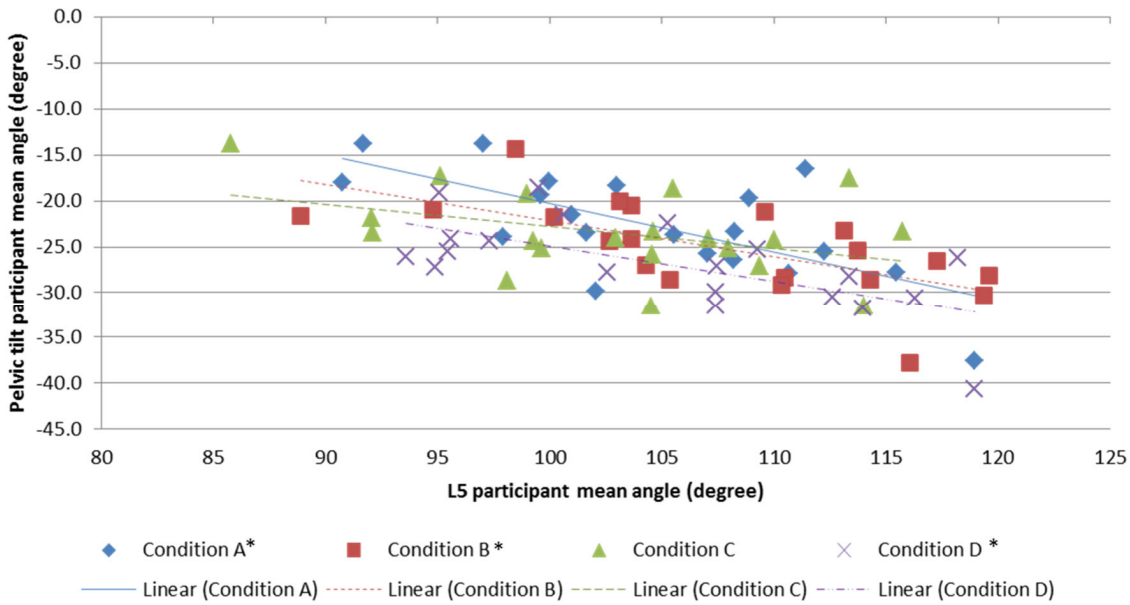

Figure 24: *Relationship between seated participant L5 and pelvic tilt mean angles for the four study conditions (n = 20). *Statistically significant p ≤ 0.010.*

These relationships have the potential to estimate spinal curvature in data collected with accelerometers within a vehicle, where spinal curvature could not be measured.

3.5.2 Anthropometry and posture angle relationships

There were ten statistically significant ($p \leq 0.010$) relationships between the anthropometry measures; the seated posture angles in Condition A—no footrest, no PPE, and the standing reference posture angles (Table 11).

Table 11: *Statistically significant ($p \leq 0.010$) relationships between anthropometric measurements, Condition A—no footrest, no PPE seated posture angles, and the standing reference posture angles. Relationships were evaluated with Pearson's product-moment correlation coefficient (r).*

Anthropometric measurement	Posture angle	Pearson's product-moment correlation coefficient (*r*)
Waist circumference (mm)	Seated thigh angle	$r(20) = -0.588$, $p = 0.006$
	Seated thoracic spine angle	$r(20) = 0.687$, $p = 0.001$
	Seated lumbar spine angle	$r(20) = -0.567$, $p = 0.009$
	Standing lumbar spine angle	$r(20) = -0.610$, $p = 0.004$
Weight (kg)	Seated thoracic spine angle	$r(20) = 0.723$, $p < 0.001$
	Standing thoracic spine angle	$r(20) = 0.607$, $p = 0.005$
	Standing lumbar spine angle	$r(20) = -0.585$, $p = 0.007$
Sitting knee height (mm)	Seated thoracic spine angle	$r(20) = 0.623$, $p = 0.003$
Sitting buttock to knee length (mm)	Seated calf angle	$r(18) = -0.703$, $p = 0.001$
Sitting buttock to popliteal length (mm)	Seated calf angle	$r(20) = 0.595$, $p = 0.006$

Participant's waist circumference had a moderate relationship with the Condition A seated thigh angle, the seated thoracic spine angle, and both the seated and standing lumbar spine angles (Figure 25).

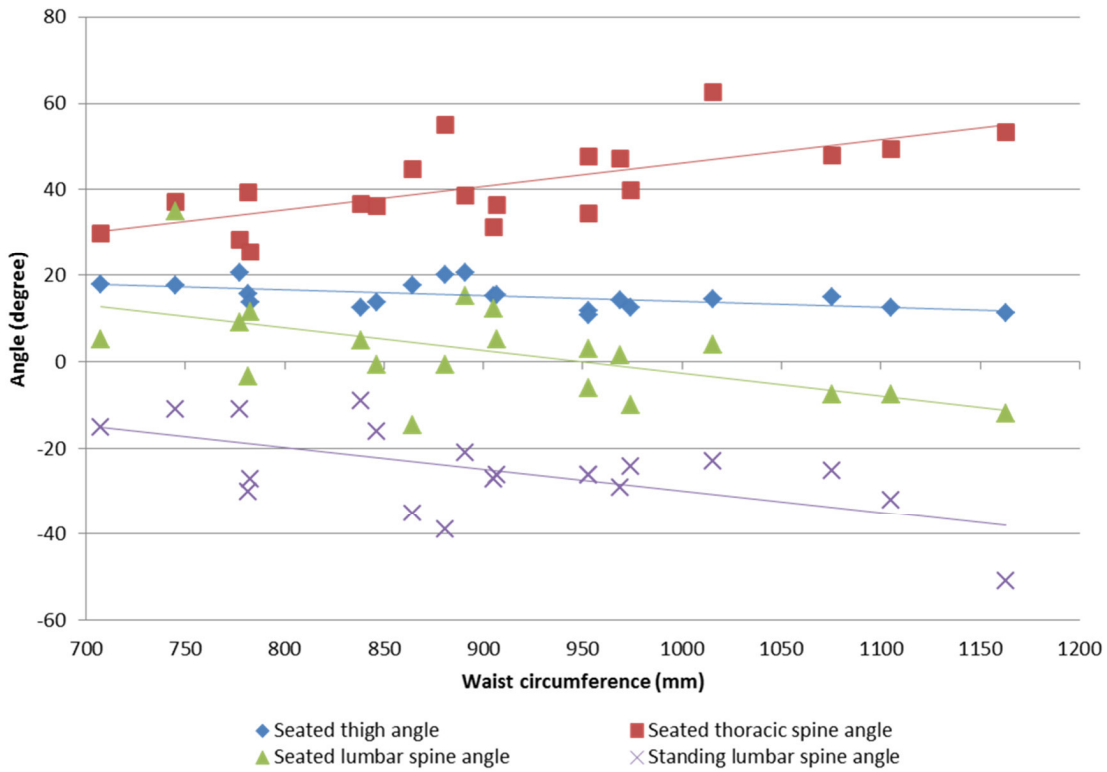

Figure 25: *Waist circumference statistically significant relationships with Condition A seated posture angles and the standing reference posture angles (n = 20).*

The seated thoracic spine angle had an increased kyphosis (spinal processes diverging, see Section 2.6.1, Figure 8) with an increasing waist circumference (red squares). There was a mild decrease in hip flexion with the increased waist circumference (blue diamonds). The standing lumbar lordosis (spinal processes converging, see Section 2.6.1, Figure 8) increased with an increased waist circumference (purple cross), and the seated lumbar spine went from a slight kyphosis to a mild lordosis with the increased waist circumference (green triangles).

The participants' weight had a moderate relationship with the seated and standing thoracic spine angle, and the standing lumbar spine angle (Figure 26).

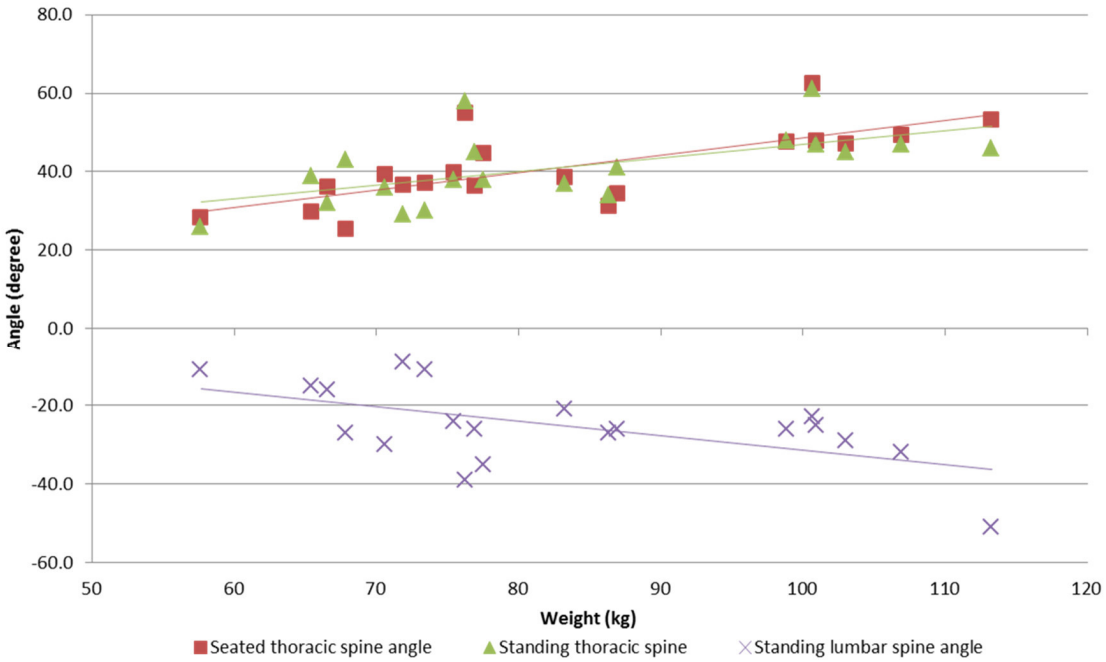

Figure 26: *Weight statistically significant relationships with seated posture angles (n = 20).*

The seated and standing thoracic spine angles both showed an increased kyphosis with an increased body weight (red squares and green triangles, respectively). The standing lumbar lordosis increased with increasing body weight (purple crosses).

The increasing sitting knee height had a moderate relationship with an increasing kyphosis of the seated thoracic spine (Figure 27).

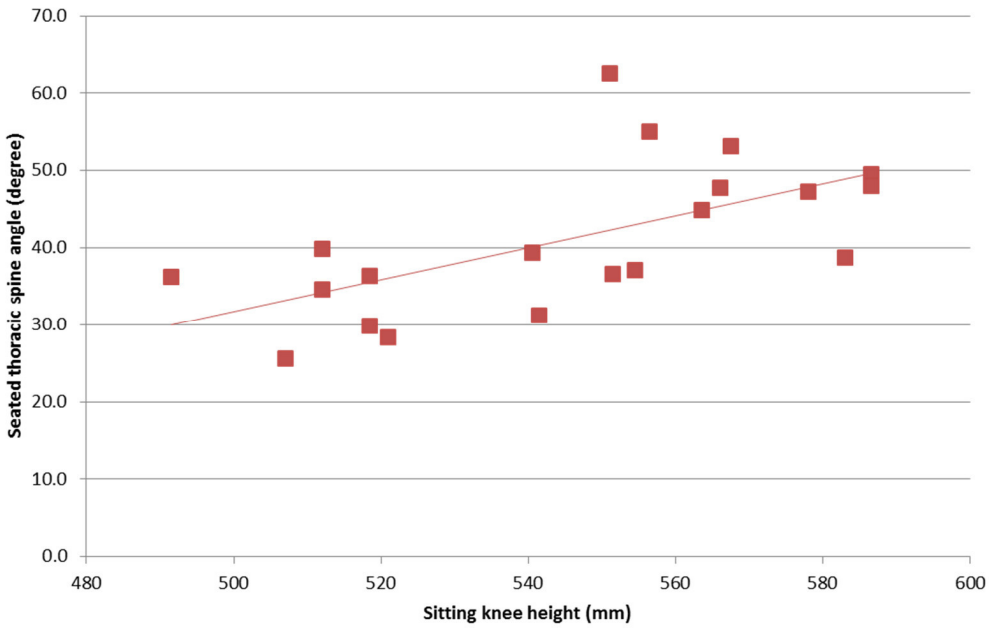

Figure 27: *The statistically significant ($p \leq 0.010$) relationship between the sitting knee height and the seated thoracic spine angle ($n = 20$).*

Both the sitting buttock to knee (blue diamonds) and buttock to popliteal (red squares) lengths had a moderate relationship with the seated calf angle (Figure 28). Both followed a transition from knee extension (>0°) to knee flexion (<0°) with increased length.

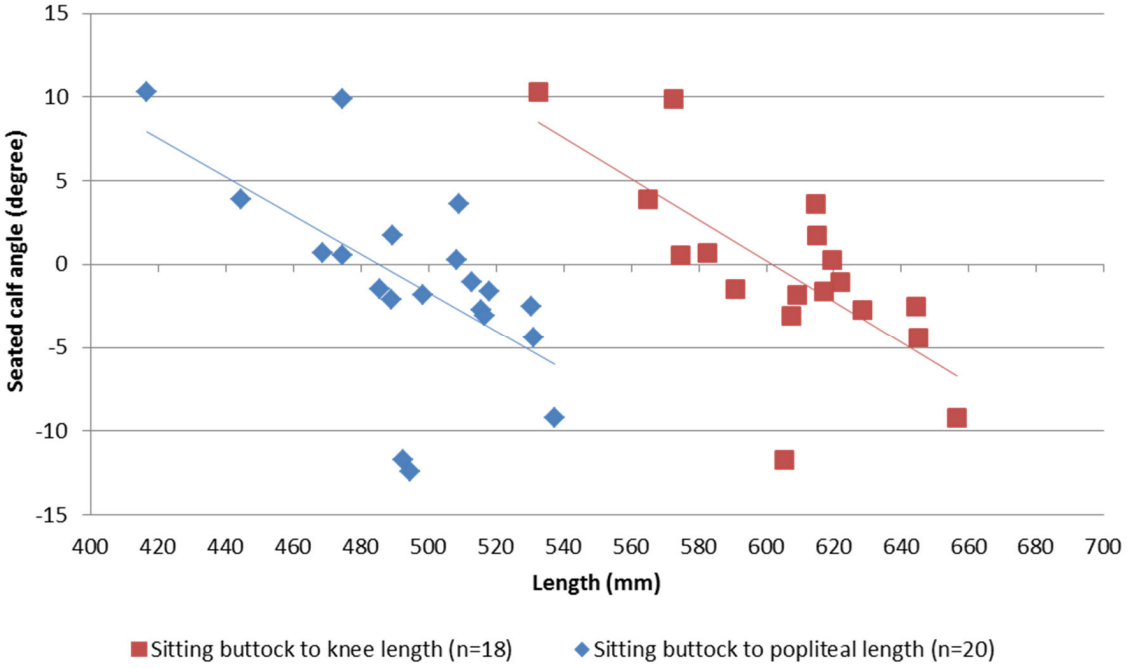

Figure 28: *The statistically significant relationships between the seated calf angle with sitting buttock to knee and buttock to popliteal lengths (n = 20).*

4 Discussion

This study looked at the spinal curvature when seated in the pseudo-LAV LORIT passenger seat. Spinal posture changes from standing to seated, and the seated spinal posture may be influenced by the backrest and seat pan angles. The study results suggested that the techniques were useful; however, further validation of these methods, as well as considering new technologies and methods would be beneficial while assessing other vehicle seats.

4.1 Study limitations

Limitations of the study were the absence of a head rest, and no seatbelt use, though a seatbelt was available on the universal seat. We wanted to see a wider range of differences between seated postures, the use of the seatbelt would have influenced the participant's posture. Anecdotally, the seatbelts are not worn domestically. However, when the threat level was considered real, soldiers were believed to be wearing the seat belts while in theatre.

The gaps in the backrest and seat pan may have influenced participant's seated postures. The open spaces created areas without support to the rear-centre buttocks and the back centre (see Section 2.1, Figure 1). Participants may have adjusted their seating posture to reduce the unsupported portions.

The pseudo-LAV LORIT floor was a bar, similar to the footrest, which limited the leg posture of participants. In the vehicle soldiers may have placed their feet further away or closer to the seat given the space and the opportunity to do so. The leg positions observed in the pseudo-LAV LORIT passenger seat may be less realistic for some. Similarly, leg space while in the laboratory environment was not limiting like in a full rear cabin with up to seven soldiers at once. It was observed that participants would have knees falling to the sides when seated. In the LAV, with a full compliment of soldiers in the rear area, knees may be at a more upright posture due to restricted space.

The L5 accelerometer was the most difficult to use as that area of the body tended to have more movement of the skin, muscle and lipid tissues. This area of the body was also found to produce moisture during experimentation, where the medical tape would either move or fall off. There was sometimes the presence of body hair, which in hind sight, could have been removed prior to placing the accelerometer. The data collected in this area may therefore be less precise where no or very little movement was found with the other accelerometers. The L5 accelerometer was also sometimes against the backrest which was seemingly uncomfortable for approximately 25% of participants as they would shift their back to place the L5 accelerometer within the gap of the backrest, or completely against the backrest. If their seated posture placed the accelerometer half in and half out, it seemed uncomfortable, the medical looked to be pulling, and the seated posture was modified by the participant without observer influence.

The seated postures were maintained for short periods of time, a lengthier experiment may have seen posture differences over time due to soldier readjusting their postures. Well rested participants may also have influenced their postures. After a long patrol, for instance, the soldiers may not sit in the LAV LORIT passenger seat in the same manner. Our current study would not be capturing those changes or effects.

4.2 The seated posture

The act of sitting changes the spine's natural standing curve. The lumbar lordosis seen in a standing posture decreases in the seated posture, it becomes neutral or even kyphotic (De Carvalho et al., 2010; Bae et al., 2012; Cho et al., 2015; Claus et al., 2016). These changes also change spinal compression forces between the vertebrae. Compression forces are larger while seated at a 90° angle compared to a 120° seated angle. Additionally, lumbar pads decrease spinal compression further (Pheasant and Haslegrave, 2006). The pseudo-LAV LORIT passenger seat backrest angle was set at 106°. In the absence of a lumbar pad, the expected spinal compression would range between 400 N to 500 N according to Andersson et al.'s (1974) study results as reported by Pheasant and Haslegrave (2006), therefore backrest angles are considered optimal between 100° to 110°. Our pseudo-LAV LORIT passenger seat was within this range, however, other LAV seats were found to be at <100° (Chafé et al., in press).

4.2.1 Standing to seated differences

The differences observed from the standing to the seated postures were greater at the pelvic tilt and the lumbar spine. Similar results have been reported by other researchers. De Carvalho et al. (2010) reported a lumbar spine difference of 43°, and a sacral inclination[1] difference of 44° from standing to seated in a car driver type seat with a 100° backrest. A second group reported a lumbar lordosis difference of 19° from standing to seated in a 90° backrest (Cho et al., 2015), while, Bae et al. (2012) reported a lumbar spine 20° difference between standing and seated postures, however the backrest angle was not reported. We observed a 27° lumbar spine difference, and a 35° pelvic tilt difference, these values were within the ranges previously observed.

4.2.2 Added footrest

In Condition comparisons of A to B, and C to D, feet were moved from the floor bar to the footrest bar. This significantly changed the seated posture as reflected in the pelvic tilt, as well as the mean thigh, calf and boot angles. These changes were also observed in the previous study within the LAV (Chafé et al., in press). Other researchers have looked at the effects of sitting on the floor with their legs crossed. The lumbar spine angle was reduced from standing by 36° and 54° respectively (Bae et al., 2012; Cho et al., 2015). The footrest could be considered as having a similar effect as the knees were raised in all instances.

The transition from Condition A to B generated an increased torso extension, however this was not observed within the transition of Condition C to D. The difference between A–B and C–D was the PPE. Our previous study also looked at the influence of footrest use while wearing PPE (Chafé et al., in press). A statistically significant difference of 4° was observed at L5 when feet were placed from the floor to the footrest, but not the footrest across. The footrest across was the setting of our pseudo-LAV LORIT passenger seat. The absence of a significant difference could be considered a similar result in both studies. It would suggest that the PPE was preventing the torso extension that arises from raising the feet onto the footrest across in the LAV LORIT passenger seat.

[1] De Carvalho et al. defined sacral tilt as: "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."

4.2.3 Added PPE

The comparison between Conditions A versus C and B versus D assessed the effect of adding PPE, which resulted in an increased hip flexion. The extra bulk of the ballistic plate and the fragmentation vest may have pushed the buttocks in the horizontal axis further away from the backrest with feet placed on the same bar, creating and increased hip flexion. Other research groups also reported that PPE pushed the hip forward (Reed and Ebert, 2013; Chafé et al., in press).

The addition of PPE experienced when transitioned from Condition B to D resulted in an increased pelvic tilt and increased lumbar kyphosis that was not observed between Conditions A to C. As Conditions B and D also had feet placed on the footrest, the PPE may have pushed the hips forward slightly and amplify the effect of the footrest on the pelvic tilt extension and lumbar kyphosis.

One participant had a distinct seating posture (i.e., torso flexion rather than extension); the addition of PPE decreased torso flexion (i.e., C7 angle) by 15° and 10°, without and with footrest respectively. The mean group C7 angles were not different among the four conditions, ranging from 93° to 95°. The large difference suggests that the bulk of the loaded tactical vest, as well as the rigidity from the forward and rear ballistic plates, reduced the torso flexion of this unique participant. The remainder of the group was in torso extension where PPE does not show an effect at the C7 angle. Reed and Ebert (2013) found that the effects of PPE and the encumbered levels that they assessed required more space in the waist area supporting the possibility that the increased bulk in the waist area influenced the participant's forward posture.

4.2.4 Added footrest and PPE

The differences observed with the transition of Condition A (no PPE, no footrest) to Condition D (PPE and footrest) manifested themselves at the thigh, calf and boot angles, as well as the pelvic tilt, lumbar region, and the L1/L2 vertebral segment.

The group calf mean angle and the boot mean angle differences that resulted from the transition of Condition A to condition D were believed to be influenced by the footrest rather than the PPE. Results described in Sections 3.4.1—Condition A to B, and 3.4.6—Condition C to D, demonstrated equivalent changes to the mean angles of Section 3.4.3—Condition A to D (i.e., 6° and 5° increased knee extension, respectively; 4° and 4° increased ankle flexion, respectively).

The increased hip flexion with the PPE and footrest was 3° and 2° more than with only the transition to the footrest (A to B, and C to D, respectively). The addition of the PPE alone increased hip flexion by 2° and 3° during the transition from A to C, and B to D, respectively. This suggests that the combination of PPE and footrest had a cumulative effect on the group mean thigh angles.

The pelvic tilt mean differences showed a similar response to the thigh mean angles in that the pelvic tilt with the added footrest (Section 3.4.1—Condition A to B) showed an increased pelvic extension. Then an increased pelvic extension was added with PPE (Section 3.4.5—Condition B to D). When both PPE and the footrest were used, a greater increased pelvic extension was observed, a cumulative result. However, when considering the pelvic tilt results of Section 3.4.6- Condition C to D, adding only the footrest while wearing PPE in both conditions, a similar pelvic extension increase was also observed. Participants in the C and D conditions were wearing PPE, and the C to D differences were expected to be the result of the added footrest.

There was an increased lumbar kyphosis when wearing PPE, and with feet placed on the footrest (Section 3.4.3—Conditions A to D). A smaller increased lumbar kyphosis was also observed with added PPE in section 3.4.5—Condition B to D. However, participants in Condition B and D both had feet placed on the footrest. These results were not cumulative where adding both the PPE and footrest resulted in a 6° change, while adding just the PPE resulted in a 4° change. When looking at just adding the footrest, no significant differences were found at the lumbar spine region, nor was there a significant change with just the PPE while feet were placed on the floor bar. The lumbar spine region was influenced with the combination of PPE and footrest together.

A 1° increased kyphosis was observed between the L1 and L2 vertebrae segment. This difference was also observed with the addition of the footrest, however only when also wearing PPE (Section 3.4.6 Condition C to D). Suggesting once more that the effects were dependent on the presence of both the PPE and footrest.

4.2.5 Removed footrest and added PPE

The transition from Condition B to C manifested a removal of the feet from the footrest with the addition of the PPE onto the body. There were no significant differences within the spinal curvature. The body posture angles demonstrated a hip extension, a knee extension, and an ankle extension almost equivalent to the addition of the footrest. The hip extension was a few degrees smaller (2° and 3° respectively) than the hip flexion observed under Condition transitions A to B and C to D. This difference could be due to the presence of PPE, as a similar result was observed with the transition of Conditions A to C, B to D, and A to D, the PPE increased the hip flexion.

The presence of PPE may have increased the hip flexion, resulting in a lesser decrease when the feet were removed from the footrest.

4.3 Body posture and spinal region angle relationships

The relationships found between the body posture angles and the spinal region angles may predict what the seated posture will look like. The C7 body angles showing a torso flexion would predict a lumbar kyphosis. These observations were also reported indirectly within Cho et al. (2015), where they evaluated an anterior support seat, sitting on a stool, and seated on the floor cross-legged. Though the C7 angle or the torso angle was not measured, the images of the seated postures demonstrate a forward posture. They report the lumbar angles as kyphotic for the anterior support and cross-legged and a neutral lumbar spine for sitting on the stool.

The L5 body angles showing an increasing torso extension were reflected in an increasing pelvic tilt. The L5 vertebra and sacrum are structurally joined at the base of the spinal column and pelvis. The L5 body segment angle has the potential to predict the pelvic tilt, however accelerometers placed at the L5 location were more susceptible to movement due to extendable skin. It was also observed that participants would sometimes shift their posture to give the accelerometer more space; it may have been uncomfortable between the back and backrest causing a number of participants to shift their posture and place the accelerometer in the backrest gap to avoid the instrument pushing into their back. Other techniques and technologies may be better suited for this specific area of the body.

4.4 Anthropometry and body posture relationships

4.4.1 Waist circumference

Waist circumference was found to have a relationship with four body posture measurements within this study. The seated thoracic spine showed a more pronounced kyphosis with the increased waist circumference. An increased waist circumference suggests more weight within the abdominal area that may be pulling the shoulders down into a slouching posture.

The decreased hip flexion can also be explained by the increased weight at the abdominal area that may be pushing down the thigh towards a hip extension.

The increased standing lumbar lordosis may also be influenced by the presence of more tissue in the abdominal area, pulling the front of the lumbar vertebrae to the front, increasing the lumbar lordosis angle.

The lumbar region angle transitions from a lordosis to neutral to a kyphosis from the standing to the seated posture. This effect seems to have been influenced by the waist circumference where a larger waist circumference maintained a lumbar lordosis when seated.

4.4.2 Weight

The thoracic spine angle, both in seated and standing postures, had an increased kyphosis alongside an increased weight. A possible explanation is that the increasing weight was distributed on the body in a way that pulled the upper torso towards the front and down, hence increasing the thoracic kyphosis.

The standing lumbar angle also showed a similar relationship where the lumbar lordosis increased with increasing weight; potentially the increased lordosis was due to an imbalance of the body centre of gravity.

4.4.3 Sitting knee height

The seated thoracic spine angle showed an increased kyphosis with an increasing sitting knee height. We can postulate that the increased knee height resulted in an increased hip flexion, which may have in turn rounded the back up to the thoracic spine.

4.4.4 Sitting buttock to knee and buttock to popliteal lengths

The sitting buttock to knee and buttock to popliteal lengths both showed a similar relationship with the seated calf angle in Condition A. Shorter lengths represented a knee extension, and the longer lengths presented a knee flexion. As feet were positioned on a fixed point relative to the seat (i.e., the floor bar, see Section 2.1.1, Figure 2), the longer lengths would have placed the knee further forward of the floor bar, creating a knee flexion. Similarly, the shorter lengths pulled the knee away from the floor bar creating a knee extension when the feet were positioned in the same location on the floor bar. The calf angle would also have been influenced by the participant's foot placement onto the floor bar, when considering did participants place their foot centre on the bar, the bar under their toes, or the bar under their heel. No guidance from observers was given to participants other than to sit comfortably as they believed they would in the actual LAV.

4.5 Under clothing spine curvature tools

Other tools, such as the Luna Inc. fiber optic positioning sensor, may also be worth evaluating (Whitestone et al., 2018). The fiber optic cable can be worn under the clothing and PPE to capture the naturalistic posture of individuals directly in the vehicle. There is also the potential to use this tool within active vehicle exercises rather than a static mock up. This type of tool may also be able to decipher postural shifts resulting from long-term seating, or fatigue during a longer time span. The Epionics SPINE system can also be used under clothing and should also be considered as a potential new technique (Consmüller et al., 2012; Pries et al., 2015).

5 Conclusion

The techniques used to characterize spinal curvature and body segment angles seem to be able to distinguish the effects of body posture changes due to footrest use, as well as the use of PPE. These techniques have been used by other researchers and clinicians; however, time and naturalistic limitations do exist. The accelerometers may shift with increased movements and do not actually inform on the spinal curvature. The spinal mouse has been shown to be effective in measuring spine curvature; however, access to the bare skin spine is a must.

5.1 Recommendations

1. Assess different vehicle seats in order to determine the variability resulting from variable backrest angles.

2. Consider comparing the use of underclothing spine curvature measuring tools such as Luna Inc. positioning sensors or the Epionics system.

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Annex A Step by step procedure

1. Send participant info sheet with trial requirements.
    1.1. Helmet.
    1.2. Combat shirt.
    1.3. Combat boots.
    1.4. Sports shorts.
    1.5. Undergarments.
    1.6. For females—specify rear clasping bra.
    1.7. Snacks.
    1.8. Water bottle.
2. Send visitor notification to commissionaires.
    2.1. Have participant information, and advise of wireless instruments being used in Room 111.
    2.2. Give contact information. Capt Chafé ext. 4682 or ext. 4758, Rania Issa ext. 4938.
3. Prepare for participant.
    3.1. Prepare folder for participant in experiment folder.
    3.2. Open anthro sheet for participant.
    3.3. Prepare Delsys system—make sure all charged and connected to computer.
    3.4. Prepare Delsys acquisition software.
        3.4.1. Workflow environment.
        3.4.2. Test config manager.
        3.4.3. Select 5 accelerometers.
    3.5. Confirm Bluetooth antenna on.
    3.6. Prepare Valedo software.
    3.7. Open Valedo participant sheet to be filled in.
    3.8. Prepare anthro bench.
    3.9. Have universal seat in place and in proper configuration for the LAV LORIT passenger seat.
    3.10. Have modified PPE available.
    3.11. Have printed consent form, questionnaire, Section 32 signed paysheets and participant key in Prot B folders.
    3.12. Have printed anthro sheet and condition sheet with condition matrix.
    3.13. Prepare anthropometric instruments.

3.13.1. Set spreading caliper to 6 cm.

3.13.2. Anthropometer.

3.13.3. 30 cm ruler.

3.13.4. Goniometer.

3.13.5. Measuring tape.

3.13.6. 3 ft. level.

3.14. Prepare anthro documents.

3.14.1. Notes.

3.14.2. Worksheets.

4. Meet participant at gatehouse.

4.1. Show participant emergency rally point.

4.2. Escort participant to Room 111.

4.3. Place trial in progress sign on outside of door.

4.4. Make sure door is unlocked but closed.

5. Participant in-brief.

5.1. Go over consent form, info sheet and explain procedure for the day.

5.1.1. Landmarks drawn.

5.1.2. Anthropometry measures—mention that anthro seat is a bit unsteady.

5.1.3. Accelerometers placed with medical tape—if participant hairy, may need to shave.

5.1.3.1. Show accelerometers (Unit 2).

5.1.4. Spinal mouse reference measures.

5.1.4.1. Show spinal mouse.

5.2. Ask if they have questions, answer questions.

5.3. Participant signs, witness signs and investigator signs.

5.4. Advise of emergency exits, rally point and facilities (washroom, smoking area).

5.5. Determine participant code.

5.5.1. First 2 letters mother's maiden name.

5.5.2. Last 2 numbers from service number.

5.5.3. Last 2 letters father's name.

5.5.4. Use this code to name all files Xx99xx.

5.5.5. Write participant code on sticky note and place on laptop for daily reference.

5.6. Fill in participant key with information.

5.7. Prepare Valedo participant sheet.

5.8. Give paysheet to participant to fill in for participant pay (military members only).

5.9. Weigh helmet.

6. Participant back pain questionnaire.

6.1. Go over results—if yes in questionnaire, ensure participant knows they can tell us they need a break at any point, and can stop data collection as required.

6.2. Instruct participant to get ready for anthropometry—undress to undergarments.

6.3. Show coat rack for clothes.

7. Participant undress for anthropometry (undergarments only).

7.1. Leave room, give privacy to participant.

7.2. Make copy of signed consent form.

7.3. Lock up participant key and signed consent form (original).

8. Find and mark landmarks.

8.1. Tell participant what you are going to do, ask marker or eyeliner? Show pictures.

8.1.1. Find right acromion.

8.1.2. Cervicale (C7 spinous process).

8.1.3. 6 cm right of cervicale.

8.1.4. Find and mark PSIS.

8.1.5. Draw line between the PSIS

8.1.6. Measure 2 cm below for S3—anal crease.

8.1.7. Use right PSIS for L5 vertebra accelerometer placement.

8.1.8. Omphalion anterior.

8.1.9. Omphalion posterior.

8.1.10. Right suprapatella.

8.1.11. Right popliteal fossa.

9. Anthropometry measures.

9.1. One person measures, one person transcribes on laptop.

9.2. Note allowable error for duplicates.

9.3. Take measurements till AE good.

9.4. Measure body weight (and helmet weight if not already done).

9.5. Position participant in Frankfurt position (horizontally align upper edge of the external opening of the ear canal (auditory meatus) and the lower edge of the eye socket (orbital margin)).

9.5.1. Measure stature.

9.5.2. Acromial height.

9.5.3. Waist circumference.

9.6. Adjust anthropometric seat to have participant seated at 90° (legs and torso), and head in Frankfurt plane.

9.6.1. Measure sitting height.

9.6.2. Acromial height, seated.

9.6.3. Popliteal height.

9.6.3.1. Flip measuring rod (add 10 mm).

9.6.3.2. Mark accelerometer landmark at 0.75 (from floor) popliteal height. [Or 0.25 from popliteal].

9.6.3.3. Measure leg width.

9.6.3.4. Mark accelerometer landmark at half leg width.

9.6.4. Seated knee height.

9.6.4.1. Flip measuring rod.

9.6.5. Seated buttock to knee length.

9.6.5.1. Measure correction distance from edge of ruler(s) [remove 18 mm].

9.6.6. Seated buttock to popliteal length.

9.6.6.1. Flip measuring rod (add 10 mm).

9.6.6.2. Measure correction distance from edge of ruler(s) [remove 18 mm].

9.6.6.3. Mark accelerometer landmark at half butt-popliteal length.

9.6.6.4. Measure thigh clearance

9.6.6.5. Mark accelerometer landmark at half thigh clearance.

10. Accelerometer placement.

10.1. Make sure green lights can be seen.

10.2. Make sure buttons are accessible.

10.3. Secure with 2 pieces of tape each.

10.3.1. Acc 3 on C7, arrow pointing up towards ceiling (head).

10.3.2. Acc 4 on L5, arrow pointing up towards ceiling (head).

10.3.3. Acc 5 on side right thigh, with participant sitting place sensor arrow pointing up towards ceiling (head) (sensor should be parallel to floor when participant standing).

10.3.4. Acc 7 on side right lower leg, arrow pointing up towards ceiling (knee).

10.3.5. Acc 8 on boot, top of the toe with arrow facing towards participant ankle.

10.3.6. Pair sensors to computer.

10.3.7. Take photo of accelerometer placement.

10.3.7.1. Indicate photo ID.

11. Spinal mouse reference measurements.

11.1. Explain reference measurements will be for individual mobility.

11.2. Turn on computer Bluetooth.

11.3. Start with standing warm up of back, back and forth, rotate.

11.4. Take measurements 3 standing postures.

11.4.1. Select Valedo mouse software.

11.4.2. Select participant.

11.4.3. Select standing posture.

11.4.4. Participant standing, arms relaxed to side, normal posture.

11.4.4.1. Select <eye> F9 and confirm correct participant.

11.4.4.2. Select + F2—follow screen instructions.

11.4.4.3. Confirm correct posture, and record time.

11.4.4.4. Place spinal mouse on C7 landmark.

11.4.4.5. Click left button.

11.4.4.6. Wait for tone.

11.4.4.7. Scroll mouse down to S3 landmark.

11.4.4.8. Click left button and wait for tone.

11.4.4.9. Select next position with right button.

11.4.5. Participant bend forward as far as possible, arms hanging down, knees straight.

11.4.5.1. Repalpate for C7, marking will have moved.

11.4.5.2. Repeat Steps 11.4.4.4 to 11.4.4.8.

11.4.6. Arms crossed, bend back as far as possible, no hip movement, knees straight.

11.4.6.1. Repeat Steps 11.4.4.4 to 11.4.4.7.

11.4.6.2. Select <save> F6 to save data.

11.5. Participant can wear shorts (if not already) and reversed combat shirt.

11.6. Test accelerometers.

11.6.1. In Delsys acquisition software, select <5 accelerometers>.

11.6.2. Name run Xx99xx_test.

11.6.3. Start recording and ask participant to move (10 seconds).

11.6.3.1. Confirm all accelerometers are collecting data in movement.

11.6.3.2. Press stop.

11.6.3.3. Return to task list.

11.7. Position participant in seated 90° posture.

11.7.1. Turned sideways on anthro bench.

11.7.2. Hip and knee angles are 90.

11.7.3. Confirm spinal mouse inclination at 0° (equivalent to our seated 90) seated posture, save file.

11.8. Collect 90° seated posture angles (angular zero) with accelerometers.

11.8.1. Name run XX99xx_90.

11.8.2. Start recording (15 seconds).

11.8.3. Return to Task list.

11.9. Take photo of 90 position.

11.9.1. Indicate photo ID.

12. Ready for data collection.

12.1. Check condition for participant dress.

12.2. Let participant get dressed for experiment.

12.3. Turn on accelerometers.

13. Help participant get dressed as per condition matrix.

13.1. Reversed combat shirt.

13.2. Frag vest.

13.3. Tac vest.

13.4. Helmet.

14. First condition measurements (seated 1 min, stand, sit 1 min, stand, sit 1 min).

14.1. Repetition 1 [Note : full sequence is Repetition 1 Acc, then Mouse; R2 Mouse, then Acc; R3 Acc, Mouse. This allows saving R1 mouse and R2 mouse in the same file, **make sure** to **switch** postures in spinal mouse software (i.e., sitting straight to sitting forward)].

14.2. Select Delsys acquisition software.

14.2.1. Select 5 accelerometers.

14.2.2. Label run Xx99xx_Condition code (A, B, C, or D) test (ex. XX99xx_Atest).

14.2.3. Start recording (10 seconds) to test accelerometers.

14.2.3.1. Ask participant to move during recording and ensure accelerometers are recording properly.

14.2.3.2. Stop recording.

14.2.3.3. Return to task list.

14.3. Ask participant to sit comfortably in seat, trying to imagine being in the back of a LAV LORIT (show photos).

14.4. Instruct participant to stay still till finished recording measurements (photo, accelerometer and spinal mouse).

14.5. Take photo of seated posture.

14.5.1. Record photo ID.

14.6. Select next subject, label run Xx99xx_Condition code (A, B, C, or D) and replicate (ex. XX99xx_A1).

14.6.1. Start accelerometer recording (15 seconds).

14.6.2. Select task list.

14.7. Select Valedo mouse software.

14.8. Select participant.

14.8.1. Select sitting posture.

14.8.2. Select + F2—follow screen instructions.

14.8.3. Place orange line of spinal mouse on C7 landmark.

14.8.4. Click left button.

14.8.5. Wait for tone.

14.8.6. Scroll mouse down to S3 landmark.

14.8.7. Click left button and wait for tone.

14.8.8. Confirm data collected.

14.8.9. Place mouse in cradle.

14.8.10. R1 click right spinal mouse button and go to 14.9.

14.8.11. For R2 and R3 select <save> F6 to save data.

14.8.12. Exit form F10.

14.9. Ask participant to stand up, shake a bit, and resit comfortably as if in back of LAV LORIT.

14.10. Repetition 2 go to 14.8.3 thru 14.8.9 then 14.8.11, then go to 14.6 thru 14.6.2, then 14.10.

14.11. Repetition 3 go to 14.6 thru 14.8.12, go to 15.

15. Participant break (5 min).

15.1. Change clothing condition (changing + PPE).

16. Second condition measurement.

16.1. Go to 14.1 and follow steps.

17. Participant break (5 min).
    17.1. Change clothing condition (changing + PPE).
18. Third condition measurement.
    18.1. Go to 14.1 and follow steps.
19. Participant break (5 min).
    19.1. Change clothing condition (changing + PPE).
20. Last condition measurement.
    20.1. Go to 14.1 and follow steps.
21. Remove accelerometers.
    21.1. Gently remove tape and accelerometers.
    21.2. Offer to wipe off unattainable landmarks (back, shoulder).
    21.3. Offer them a wipe to remove remaining landmarks.
    21.4. Let participant get dressed privately.
    21.5. Thank participant for their participation.
    21.6. Give pay sheet, and remuneration substantiation form to participant to bring to their Orderly Room (OR).
    21.7. Give copy of signed consent form.
    21.8. Ask if they have any questions or comments.
    21.9. Escort participant to gatehouse.
22. Lab clean up.
    22.1. Clean accelerometers.
    22.2. Charge accelerometers.
    22.3. Clean spinal mouse.
    22.4. **Turn off laptop Bluetooth antenna.**
23. Data transfer.
    23.1. Delsys data to Excel worksheet.
    23.2. Save participant data.
    23.3. Save Valedo data to Excel worksheet.
    23.4. Save all data to USB key for later transfer.
    23.5. Transfer anthro data to Excel database and participant worksheet.

Annex B Randomized conditions

Table B.1: *The study condition randomized order per participant.*

Participant order	Condition order			
1	A	B	C	D
2	D	A	B	C
3	C	D	A	B
4	B	C	D	A
5	B	D	A	C
6	A	C	B	D
7	C	A	D	B
8	C	B	D	A
9	C	A	B	D
10	D	B	A	C
11	A	D	C	B
12	B	A	D	C
13	A	C	D	B
14	C	B	A	D
15	D	C	A	B
16	B	C	A	D
17	A	D	B	C
18	C	D	B	A
19	D	C	B	A
20	A	B	D	C

Annex C Spinal pain history questionnaire

DATE COMPLETED: _____ PARTICIPANT ID:_____

1. Please circle your age category:

16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60

2. Please indicate your sex:
   Male: ☐ Female: ☐

Please indicate if you have experienced ***Significant Spinal Pain***. For the following questions, ***Significant Pain*** refers to the presence of discomfort that intrudes into your awareness during your usual activities, and has caused you to perform at a lower level, continue despite discomfort, or modify your activity to reduce the discomfort. It *does not* refer to trivial mild aches that are easily dismissed and have no functional significance**.**

LOCATION AND PERSISTENCE OF SIGNIFICANT SPINAL PAIN

3. Current spinal pain within 12 months, did you experience significant pain in your:

	Yes	No
Neck		
Shoulder(s)		
Upper back		
Mid back		
Lower back		
Neck pain radiating down the arms		
Low back pain radiating down the legs		

4. Previous spinal pain, excluding the previous 12 months, did you ever (before) experience significant pain in your:

	Yes	No
Neck		
Shoulder(s)		
Upper back		
Mid back		
Lower back		
Neck pain radiating down the arms		
Low back pain radiating down the legs		

Annex D Mean results with standard deviation

Table D.1 presents the mean with standard deviation of the spinal regions for the four conditions evaluated.

Table D.1: *Spinal region mean angles ± standard deviation (n = 20).*

Spinal region	Condition			
	A	B	C	D
Vertical inclination	-10±8	-11±7	-9±5	-10±4
Thoracic spine	41±10	40±10	41±9	40±9
Lumbar spine	2±11	4±11	5±10	8±10
Pelvic tilt	-23±6	-25±5	-23±5	-27±5

Table D.2 presents the mean with standard deviation of the vertebra segments for the four conditions evaluated.

Table D.2: *Vertebrae segment mean angles ± standard deviation (n = 20).*

Vertebrae segment	Condition			
	A	B	C	D
T12/L1	0±3	0±3	0±2	0±3
L1/L2	0±3	1±3	1±3	1±3
L2/L3	0±4	1±3	1±3	2±3
L3/L4	1±2	1±3	2±2	2±2
L4/L5	1±1	1±2	1±2	2±2
L5/S1	0±2	0±2	0±2	1±2

Table D.3 presents the mean with standard deviation of the body segment group data for the four conditions evaluated.

Table D.3: *Body segment mean angles ± standard deviation (n = 20).*

Body segment	Condition			
	A	B	C	D
C7	94±8	95±8	93±5	95±6
L5	105±7	107±8	103±8	105±8
Thigh	15±3	27±4	17±4	30±5
Calf	-1±6	5±5	-0.4±5[a]	4±6
Boot	12±6	16±6	11±5	16±6

[a] *n* = 19

List of symbols/abbreviations/acronyms/initialisms

CAF	Canadian Armed Forces
CFAS	Canadian Forces Anthropometry Survey
cm	centimetre
DRDC	Defence Research and Development Canada
GPM	Gneupel Präzisions-Mechanik
H-pt	H-point
kg	kilogram
LAV	light armoured vehicle
LORIT	LAV operational requirements integration task
m	metre
mm	millimetre
N	Newton
OR	Orderly Room
PPE	personal protective equipment
PSIS	posterior superior iliac spine
SoSE	Soldier System Effectiveness
stdev	standard deviation

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spinal curvature; lumbar spine; light armoured vehicl; vehicle crews; seated posture

13. ABSTRACT (When available in the document, the French version of the abstract must be included here.)

We wanted to know soldier spine curvature while seated in the light armoured vehicle (LAV) LAV operational requirements integration task (LORIT) passenger seat. Recent conflicts have highlighted discrepancies in the injury risk criteria for the lower back. To breach these discrepancies, a biofidelic instrumented spine is being developed. Soldier seated spine curvature will inform the development of the instrumented spine. Spine curvature was measured with a Valdeo Shape spinal mouse in a laboratory environment on a pseudo-LAV LORIT passenger seat. The test conditions compared the effects of personal protective equipment (PPE) and the use of a footrest on spinal curvature. We observed a cumulative effect on pelvic tilt and the lumbar spine when the footrest was used while wearing PPE. The spinal curvature findings will assist in the development of the biofidelic instrumented spine. The understanding that soldier posture in theatre will change according to their PPE and the use of a footrest should be considered when developing injury risk criteria, testing protocols, as well as survivability mechanisms.

Nous souhaitions déterminer la courbure de la colonne vertébrale des soldats en position assise dans le siège du passager d'un véhicule blindé léger (VBL) de la Tâche d'intégration des exigences opérationnelles du VBL (LORIT). Lors de récents conflits, des lacunes ont été constatées relativement aux critères de risque de blessures touchant le bas du dos. Pour combler ces lacunes, une colonne vertébrale biofidèle instrumentée est en cours d'élaboration. La courbure de la colonne vertébrale des soldats en position assise orientera l'élaboration de la colonne vertébrale instrumentée. La courbure de la colonne vertébrale a été mesurée à l'aide d'un dispositif Valedo Shape Spinal Mouse sur un pseudo-siège de passager de VBL LORIT dans un environnement de laboratoire. Les conditions d'essai visaient à comparer les effets du port de l'équipement de protection individuelle (EPI) et de l'utilisation d'un repose-pieds sur la courbure de la colonne vertébrale. Nous avons observé un effet cumulatif sur l'inclinaison du bassin et la colonne lombaire lors de l'utilisation d'un repose-pieds en association avec le port de l'EPI. Les constatations relatives à courbure de la colonne vertébrale seront utiles pour la mise au point d'une colonne vertébrale biofidèle instrumentée. Il faudrait tenir compte du fait que la posture du soldat dans le théâtre sera différente selon le type d'EPI porté et l'utilisation d'un repose-pieds lors de l'élaboration des critères relatifs au risque de blessures, des protocoles d'essais ainsi que des mécanismes de surviabilité.