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Soldier System Effectiveness (SoSE) Work Breakdown Element (WBE) 1.3.5—Vehicle occupant survivability

End of project documentation

Capt Gabrielle S. Chafé
DRDC – Valcartier Research Centre

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Abstract

As part of the Soldier System Effectiveness (SoSE) project, work was performed by Defence Research and Development Canada – Valcartier Research Centre to characterise vehicle occupant postures, behaviors and performance to better ensure their survivability. Under SoSE WBE 1.3.5, soldiers were studied as vehicle occupants of light armoured vehicles (LAV). We characterized their seated postures, the influence of footrest use on those postures, as well as the influence of personal protective equipment (PPE). Understanding the seated postures within vehicles was expected to play a key role in the development of more realistic injury risk criteria, modelling, test facilities, and test protocols.

This work was performed between April 2014 and March 2019.

Résumé

Dans le cadre du projet Efficacité du système du soldat (ESSdt), le Centre de recherches de Valcartier de Recherche et développement pour la défense Canada (RDDC) a entrepris de caractériser les postures, les comportements et les activités des occupants de véhicules afin d'améliorer leur surviabilité. L'ERT 1.3.5 de l'ESSdt visait l'étude de soldats en tant qu'occupants de véhicules blindés légers (VBL). Nous avons caractérisé leurs postures assises, l'effet de l'utilisation d'appui-pieds sur ces postures, ainsi que l'influence de l'équipement de protection individuelle (EPI). La compréhension des postures assises à l'intérieur des véhicules devait jouer un rôle clé dans l'amélioration du réalisme des critères et des modèles relatifs au risque de blessure, des installations d'essai et des protocoles d'essai.

Ces travaux se sont déroulés entre avril 2014 et mars 2019.

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1 Introduction

1.1 Background

During the conflict in Afghanistan, injuries to the lower back were observed more often than expected. It called into question the current test methods and injury risk criteria that were being used. The Research and Technology Organisation (RTO) of the North Atlantic Treaty Organisation (NATO) Human Factors and Medicine (HFM)-090 Task group 25 determined that better testing instruments needed to be considered and developed (NATO, 2007). Defence Research and Development Canada (DRDC) – Valcartier Research Centre had representatives in this NATO group, and initiated the construction of a bio-fidelic instrumented spine that would yield more realistic measurements, and naturalistic reactions of the human spine. SoSE 1.3.5 was initiated to support work under land vehicle integrated survivability (LVIS) to better understand soldier equipment, postures, and behaviours to inform the construction of the bio-fidelic spine.

Seated postures have been evaluated with many techniques, such x-ray, rachiometer, accelerometers, optical tracking and pressure sensors (Bae et al., 2012; Cho et al., 2015; De Carvalho et al., 2010; Vergara and Page, 2000; Mork and Westgaard, 2009; Mörl and Bradl, 2013; Claus et al., 2016). Vehicle seated postures have been evaluated using kinematic models, and three dimensional scanners (Reed et al, 1999; Reed and Ebert, 2013).

More specifically, spine curvature has also been assessed in clinical and research settings with a spinal mouse, a less intrusive device, however the tool must be used on the skin of the spinal column (Mannion et al., 2004; Guermazi et al., 2006; Muyor et al., 2011; Lopez-Minarro et al., 2012[a]; Lopez-Minarro et al., 2012[b]).

Our experiments were focused on determining the soldier's seated posture in the light armoured vehicles (LAV). We opted for Delsys® Trigno™ accelerometers to determine body posture angles while seated in the vehicle seats. To further determine seated spinal curvature, we selected a Valedo® Shape spinal mouse to measure angles however the spinal mouse required specialized seating and specialized personal protective equipment (PPE) to gain access to the skin over the spinal column.

2 Summary of work

Two studies were put in place to understand the seated posture of soldiers within the LAV fleet. These studies were to inform the development of a bio-fidelic instrumented spine.

2.1 Problem statement

Understand the seated posture of vehicle occupants with a focus on the low back and spine curvature, as well as the influence of personal protective equipment (fragmentation vest with ballistic plates, tactical vest, and helmet) to increase soldier survivability against anti-vehicular landmine effects.

2.2 Methodology

2.2.1 Characterisation of vehicle seated occupants—2014–2016 data collection

The first study assessed the soldier's seated posture in three light armoured vehicles: 1) LAV III, 2) LAV 6 and 3) LAV LORIT. Within these vehicles, there were three different seats: 1) passenger, 2) driver and 3) turret seats, which were all different between themselves and between the vehicles (Figures 1, 2 and 3).

Figure 1: *Passenger seats of the different LAV.*

Figure 2: *Driver seats of the different LAV.*

Figure 3: *Turret seats of the different LAV.*

There were also three clothing conditions assessed: 1) baseline which consisted of shorts and a t-shirt, 2) added the fragmentation vest without ballistic plates and a loaded tactical vest, followed by 3) identical to condition 2 with the ballistic plates added (Figure 4).

Figure 4: *Clothing conditions during in vehicle assessments.*

We used the Delsys® Trigno™ wireless system with inertial accelerometers to measure body segment angles while seated within the LAV. The accelerometers measured the torso angles with sensors at the 7th cervical vertebra (C7) and the 5th lumbar vertebra (L5) relative to the vertical axis (90°), the thigh angles relative to the horizontal axis (0°), the calf angle relative to the vertical axis (0°), and the boot angle relative to the horizontal axis (0°). A subgroup of the study participants were assessed while using footrests. The LAV operational requirements integration task (LORIT) passenger seats (see Figure 1) have a footrest attached to the seat pan, using the footrest, and using the footrest on the seat across from the participant were both assessed.

As part of this study, a second subgroup of participants was assessed with the Valedo® Shape spinal mouse. The Valedo® shape spinal mouse measures the spinal curvature. The tool was used on bare skin

along the spinal column. Spinal curvature was measured in a neutral seated posture on a backless bench, followed with feet up at 20°, and at 40° still while seated on the backless bench.

Comparisons between the different seats, vehicles, clothing conditions and foot placements were evaluated with paired t-test, independent t-test, and Wilcoxon signed ranks test according to the data distributions. Statistical significance was set at $p \leq 0.015$ as determined by the Benjamini-Hochberg equation (Benjamini-Hochberg, 1995).

2.2.2 Seated spinal curvature—2019 data collection

The second study focussed on the LAV LORIT passenger seat. A universal seat was adjusted using the H-point manikin[1] to replicate the LAV LORIT passenger seat angles, referred to as the pseudo-LAV LORIT passenger seat (Figure 5). The pseudo-LAV LORIT passenger seat had a 10 cm gap in the centre of the backrest to allow access to the spinal column while seated. Similarly there was a 15 cm x 15 cm square gap in the rear of the seat pan to allow access to the sacral vertebrae. The pseudo-LAV LORIT passenger seat included a footrest which was equivalent to the footrest across in the vehicle.

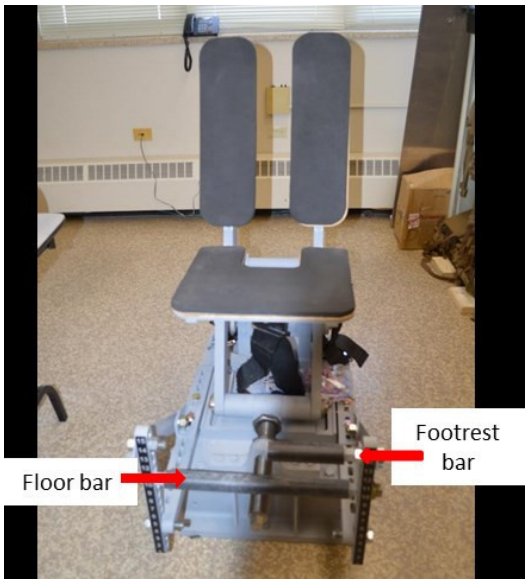

Figure 5: *Pseudo-LAV LORIT passenger seat showing the backrest gap and the rear seat pan gap. The long lower bar represents the floor, and the shorter bar represents the footrest. Two short bars were used as the footrest during the study.*

Participants were monitored simultaneously with the Delsys® Trigno™ wireless system to collect body segment angles that coincided with the Valedo® Shape spine curvature measurements. There were four conditions evaluated:

A. Combat shirt with shorts with feet on the floor;

[1] The H-point manikin is a tool developed for the automotive industry to characterize seating. The Society of Automotive Engineers (SAE) has published many standards that describe the use of the H-point manikin (i.e., J826, J1001).

B. Same as A but with feet on the footrest;

C. Combat shirt with shorts, fragmentation vest with ballistic plates, loaded tactical vest and combat helmet with feet on the floor; and

D. Same as C but with feet on the footrest.

The combat shirt was worn with the buttons to the rear exposing the skin of the centre back. The rear portion of the fragmentation vest, the rear ballistic plate and the rear of the loaded tactical vest were all cut in the centre to allow access with the spinal mouse (Figure 6).

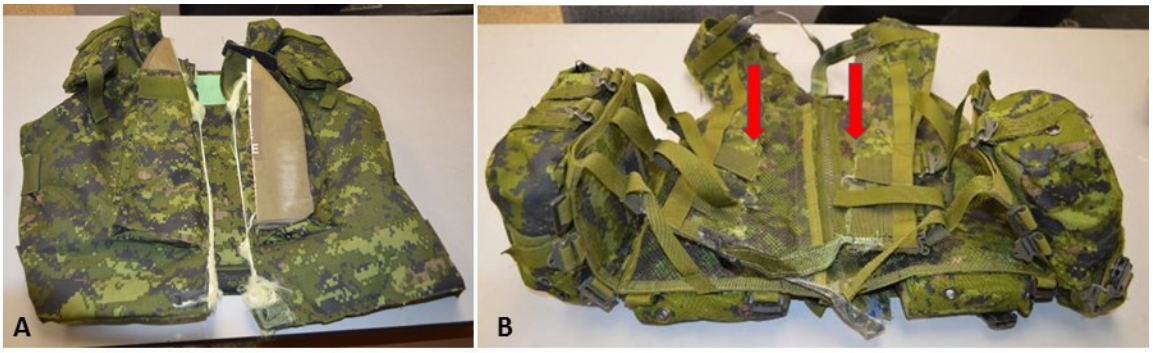

Figure 6: *A) The sliced fragmentation vest and rear ballistic plate portions. The left side of the rear pocket shown here with the ballistic plate portion inserted. B) The fully loaded tactical vest with the rear centre sliced open, red arrows indicating the cut lines.*

The four conditions were compared to each other with paired t-test or the Wilcoxon signed ranks test according to the data distribution with statistical significance set at $p \leq 0.010$.

2.3 Prime accomplishments

Within the first study, we were able to characterise the seated posture of soldiers while differentiating among the seats, vehicles, and the clothing conditions. We were able to determine that all the seats created different seated body postures. The PPE with ballistic plates influenced the torso postures in the LAV LORIT driver and turret seats. The PPE with ballistic plates also influenced the calf angles in the LAV 6 driver seat. In general, raising feet onto footrests influenced the lower back and leg angles. The footrest significantly influenced seated spinal curvature on a backless bench.

Within the second study, we were able to determine the effects of foot placement and PPE on the supported seated spinal curvature. It was observed that the footrest and the PPE together had a cumulative effect on spinal curvature and body segment angles. We showed a moderate relationship where increased torso flexion created a lumbar kyphosis. There was also a moderate relationship with an increasing torso extension and an increased pelvic extension. As part of this study we determined that certain anthropometric measurements had moderate relationships with the seated posture angles and spine curvature angles.

2.4 Operational relevance

Understanding the seated posture in the specific seats will enhance the development of the bio-fidelic instrumented spine. The bio-fidelic instrumented spine will allow the development of rigorous injury risk criteria, and will be an effective tool in monitoring new technologies that have the potential to increase soldier survivability against anti-vehicular landmine effects.

2.5 Deliverables

First study report: Chafé, G.S., T. Poirier, O. Hamel and A. Sy (in press) Light Armoured Vehicle (LAV) occupant seated postures. Defence Research and Development Canada, Reference Document, D19-0617-02234.

Second study report: Chafé, G.S., R. Issa (in press) Spinal curvature while seated in LAV LORIT passenger seat mock up. Defence Research and Development Canada, Reference Document, D19-0618-02239.

3 Conclusion

The characterisation of the seated posture informs the development of the bio-fidelic instrumented spine. For any given seat, these techniques can be used to determine the seated posture, to confirm that the bio-fidelic instrumented spine can closely reproduce and react in a similar if not identical manner. This will ensure a proper response of the instrumented spine that can be related to the vehicle users.

3.1 Recommendation

Continue to assess seated spinal curvature with the universal seat adjusted to as many LAV seats as possible to assess relative differences associated to the different seats.

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List of symbols/abbreviations/acronyms/initialisms

C7	7th cervical vertebra
DRDC	Defence Research and Development Canada
HFM	Human Factors and Medicine
L5	5th lumbar vertebra
LAV	light armoured vehicle
LORIT	LAV operational requirements integration task
LVIS	land vehicle integrated survivability
NATO	North Atlantic Treaty Organisation
PPE	personal protective equipment
SAE	Society of Automotive Engineers
SoSE	Soldier System Effectiveness
RTO	Research and Technology Organisation
WBE	Work Breakdown Element

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2459 route de la Bravoure
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Ces travaux se sont déroulés entre avril 2014 et mars 2019.