Measurement of head kinematics of snipers firing a 0.50 caliber rifle

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I. INTRODUCTION

The development of neurological impairments in specific military populations has been linked to repeated exposures from various sources of low-level blast waves, such as small explosive charges and large caliber weapons [1-4]. More recently, the development of such impairments has also been linked to the repeated firing of 0.50 caliber rifles, while some symptoms appeared to be unique to this activity [5]. The considerable amount of evidence linking blast exposure to brain trauma has led researchers to investigate the blast signature of 0.50 caliber rifles and its potential correlation to alterations in serum-based biomarkers associated with TBI [6-8]. However, it is important to consider that the firing of 0.50 caliber rifle also induces significant kinematics to the head of the shooter due to the transmission of recoil forces though the shoulder and neck. In addition, snipers routinely use suppressors with their weapon, which are known to eliminate most of the propagation of the muzzle blast towards the shooter. As such, the potential contribution of repeatedly induced head kinematics towards the development of occupational brain injuries in the sniper community cannot be disregarded. For this study, we conducted the first measurements of head kinematics of snipers during the firing of a 0.50 caliber rifle, both with and without the use of a suppressor, using a custom-built instrumented dental retainer and digital image correlation. We identified the range of peak linear and angular velocity that should be expected and defined necessary technical requirements for sensors to be used in the monitoring of such activity.

II. METHODS

A total of 15 firings were taken by two trained snipers from the Canadian Armed Forces, using a TAC-50 McMillan rifle with 12.7 mm Sniper Elite ball ammunitions. Eleven firings were conducted in the prone position and four firings were conducted in the standing position, with the rifle bipod resting on a hard surface in both scenarios. Nine firings were performed with the standard weapon configuration and six firings were performed with a BR-Tuote reflex suppressor in place of the standard barrel muzzle brake. Three weeks prior to the experimental trials, dental imprints were taken from the two participants and two custom acrylic upper teeth retainers were produced by Dentec Dental Laboratory. A DTS 6DX Pro sensor was mounted on a 3 mm thick co-moulded mounting plate to collect 6 DOF kinematic data during firing (Fig. 1(a)). To support DIC analysis, a white marker with 18 dotted faces was also attached to the front of the retainer using a 5 mm diameter co-moulded rigid attachment. Stiffness of the assembly was verified in-mouth by pushing laterally on the marker. During firing, x-y-z linear accelerations and x-y-z angular velocities were collected at a sampling rate of 1 MHz using a DAQ system with an analog 40 kHz low-pass anti-aliasing filter. High-speed videos were acquired at 20,000 fps using two Fastcam SA-Z cameras at a resolution of 1024 x 1024 pixels. The position and framing of the cameras are shown in Fig. 1(b) and 1(c). The x-y-z linear and angular displacements were computed by DIC analysis using the GOM software suite. All acquired kinematic data were post-processed in MATLAB. Linear accelerations and angular velocities were post-processed using a 500 Hz and a 50 Hz low-pass Butterworth filter, respectively. Sensor data were first migrated to the marker location to perform sensor to imagery signal validation by comparing linear velocity histories obtained from both methods. Then, sensor data were migrated from the sensor location to the head CG for further analysis.

(a) (b) (c)

Fig. 1. Photographs of (a) instrumented custom retainer and (b) camera set-up during prone firing. (c) Framing of left high-speed camera for DIC analysis during prone firing.

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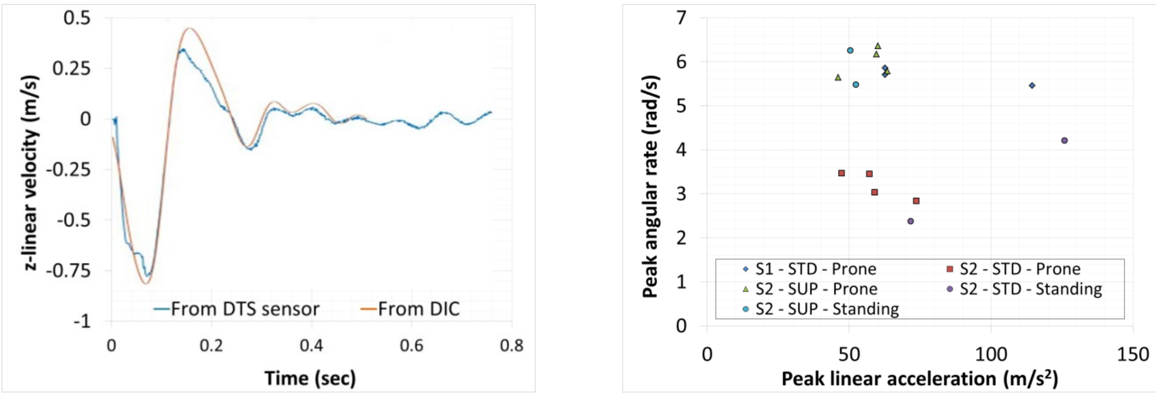
III. INITIAL FINDINGS

An example of comparison of the data collected from the DTS sensor with the kinematics data computed from the DIC analysis is shown in Fig. 2(a). A very good match was obtained for all firings and the comparison also helped identify the true signal bandwidth and inform post-processing of the sensor data. It was observed that acceleration and angular rate signals may present true signal content up to approximately 400–500 Hz and 40–50 Hz, respectively. Across all firings, single axis peak linear accelerations and single axis peak angular velocities measured at the retainer varied between ±20 m/s^2 and ±100 m/s^2 and between ±1 rad/s and ±6 rad/s, respectively. The longest observed event duration was close to 500 ms. The data migrated to the head CG demonstrated that the firing of a 0.50 caliber rifle does induce significant kinematics to the head of the shooter. Peak resultant acceleration is plotted against peak angular velocity for all 15 firings in Fig. 2(b). In general, the use of a suppressor affected the head kinematics experienced by the shooter, as the angular rate increased while linear accelerations decreased. The duration of the linear acceleration pulse appeared to increase with the use of a suppressor. The posture and stature of the shooter also affected the experienced kinematics.



(a) (b)

Fig. 2. (a) Example of linear velocity history comparison between DTS sensor and DIC methods. (b) Peak linear acceleration plotted against peak angular rate for all firings (STD: Standard, SUP: Suppressor).

IV. DISCUSSION

The levels of kinematics measured in this study warrant a deeper investigation into the potential relationship between repeated recoil-induced head kinematics and the development of neurological impairment. Such an investigation will require the means to monitor head kinematics of military personnel during the firing of sniper rifles. Existing instrumented mouth guard technologies may be good candidates for this task, however the characteristics of the data to be collected differ slightly from the kinematic data typically collected in the sport sector. Based on the event duration and signal bandwidth observed in this study, the initial recommendation is for a sensor with the capability to collect data over all 6 DOF at a minimum sampling rate of 1,000 Hz and over a minimum duration of 500 ms to confidently monitor head kinematics of snipers during training. Based on the maximum observed peak on a single axis, it is proposed that the required range for the accelerometers be a minimum of ±150 m/s^2, while the angular rate sensor should be able to collect over a minimum range of ±10 rad/s. The sensor should also be able to maintain a minimum accuracy of ±1 m/s^2 and ±0.05 rad/s, which represents approximately ±5% of the minimum observed individual peak accelerations and peak angular rate during our testing. A study on a larger population and using different weapon systems is currently ongoing and will help refine these recommendations.

V. REFERENCES

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