Quantification of Loading to the Upper Limb Behind a Ballistic Shield Using a Novel Modified ATD Arm

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I. INTRODUCTION

Behind Armor Blunt Trauma (BABT) is a non-penetrating injury that results from the rapid contact between back face armor deformations and the body. When a ballistic shield is struck by a projectile, even without penetration, it can deflect. This can result in fractures of the upper limb, leading to severe consequences for the user. Currently, National Institute of Justice standard 0108.01 is the only standard used to assess the safety of shields, which is based on whether or not projectile penetration occurs. Given that the arm may be in contact with, or close to, the back face, deflections without penetration may cause injury. As such, a tool capable of measuring loading behind a shield is needed to properly evaluate this injury risk [1-2]. The measurement of back face loading in conjunction with future injury criteria would be important for creating a standard for evaluating the safety of future shield designs. The purpose of this work was to develop an Anthropomorphic Test Device (ATD) to be used to measure the high-speed loading of the upper limb behind ballistic shields.

II. METHODS

Four vulnerable locations were identified for measurement: elbow, forearm, wrist and hand. A World SID 50th percentile upper limb ATD (Humanetics Innovative Solutions, Farmington Hills, MI) formed the basis of the new device (Fig. 1) and included an integrated six-axis load cell (forearm) and a two-axis moment load cell (elbow). Three piezoelectric 201B05 uniaxial washer-style force sensors (PCB Piezotronics Inc., Depew, NY) were added at the hand, wrist and elbow to measure the contact force to these structures. A new hand representation was designed and built, as the existing hand did not allow gripping and had no structure beneath the knuckles upon which to mount instrumentation. This hand structure was based on 50th percentile male anthropometrics and included the washer-style force sensor.

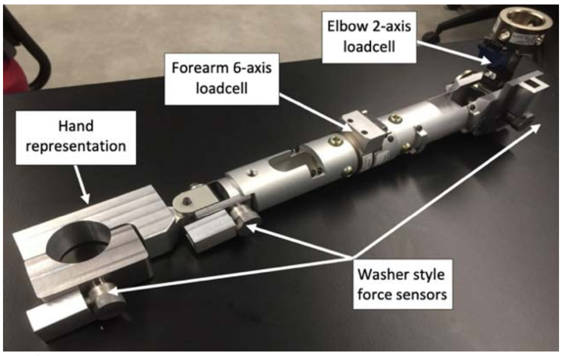

Fig. 1. Modified World-SID 50th percentile ATD upper limb to measure behind shield blunt trauma.

Ballistic testing was conducted using an IVI C21 ball projectile (9.6 g) fired at 850 m/s. The instrumented ATD upper limb was supported at the upper arm and the hand behind a ballistic shield. Its stand-off (the distance between the ATD and back face of shield) was varied between 10 mm and 40 mm and impacts were applied to different locations on the upper limb. Furthermore, two different shields were evaluated, each with different composition and geometry. The first ballistic shield design was used to test the elbow, where four impacts at both 10 mm and 20 mm stand-offs were completed. The second ballistic shield was used to test the hand, where four impacts at both 30 mm and 40 mm stand-offs were completed. Peak forces and loading durations were identified at all locations. The ATD load cell data were filtered with a two-pole 2nd order Butterworth filter with a cut-off frequency of 1,250 Hz, while the PCB data were filtered using a low pass Bessel filter with a cut-off frequency of 50,000 Hz [3]. Measurements were compared between stand-offs using a two tailed student-t test (α=0.05).

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III. INITIAL FINDINGS

The second shield underwent larger deformation for the same ballistic impact conditions, and therefore 30 mm and 40 mm stand-offs were used versus 10 mm and 20 mm stand-offs for the first shield. Increasing the stand-off distance decreased the force for both impact locations (Fig. 2). For elbow impacts, moving the stand-off from 10 mm to 20 mm tended to decrease (not significantly) the impact force by 29% and significantly increased the impact duration by 160% (p = 0.21 and <0.001, respectively). For hand impacts, moving the stand-off distance from 30 mm to 40 mm significantly decreased the impact force by 56% and showed no significant difference in the duration of impact (p=0.015 and 0.74, respectively).

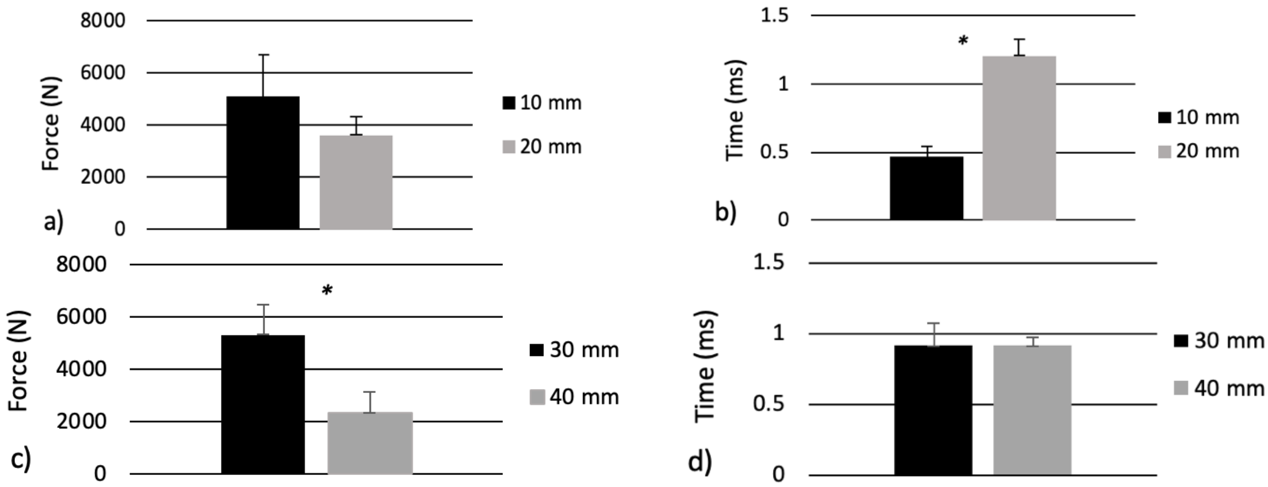

Fig. 2. Comparison of a) elbow impact force and b) elbow impact duration at 10 mm and 20 mm stand-off distances. Comparison of c) hand impact force and d) hand impact duration at 30 mm and 40 mm stand-off distances. * indicates a statistically significance difference, p<0.05.

IV. DISCUSSION

This work represents the first highly instrumented ATD upper limb capable of recording loads applied to four vulnerable regions under high force, short duration impacts. The loading was influenced by shield type, stand-off distance and impact location, and there exists a complex relationship between the peak force and impact duration. This tool may also be of interest and value to other industries, such as automotive safety. Increasing stand-off by 10 mm reduced peak forces by at least 28%, which may be a valuable method for shield manufacturers to limit arm loads and provide enhanced protection. Back face loading was highly dependent on the shield used, even when both were rated to the same ballistic level, emphasizing the importance of evaluating the back face loads for protecting upper limbs. The data collected herein will facilitate identification of regional injury limits for the upper limb, and therefore can be used for establishing a standard for evaluating new shield designs.

V. REFERENCES

[1] Pintar, F. A., *et al.*, *Traf Inj Prev*, 2002., [2] Duma, S. M., *et al.*, *J Anat*, 1999. [3] NATO, Mine Threats, 2006.