Evaluation of normalization approaches for developing temporal corridors in oblique side impacts

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INTRODUCTION

Any mechanical experiment using biological materials such as human cadavers, whether intact or component subsystems, has variability. The variability stemming from the use of the surrogate may be in the form of demographic measures such as stature, age and total body mass, or physical/material properties. Experimental design can also introduce variability depending on the interaction of the load-delivering device with the specimen. Pendulum impacting surface delivering the loading to a stationary surrogate induces different variability than sled equipment delivering the side impact load to a moving surrogate. Primary responses such as force-time and deflection-time metrics are 'assembled' from a group of tests to derive corridors and, in order to synthesize data from different tests, it is important to account for inter-subject variations. Different normalization methods are used in the impact biomechanics to accomplish this goal. The equal-stress equal-velocity approach in 1976 and impulse momentum approach in 1984 have been commonly used by regulators, researchers in academia and international organizations [1-3]. The former approach relies solely on the total body mass and is the simplest and test independent, while the latter approach is more rigorous and considered superior as it incorporates test specificity and relies on more variables measured during the test. At the International Conference on the Enhanced Safety of Vehicles in 2013, an extension/modification of the latter approach was proposed as a potential improvement [4]. The outcomes from these methods were compared using data from previously conducted pure lateral vector-induced side impact tests with stationary and non-anthropometry-specific load-wall experiments in 2002, and pendulum impact tests conducted in 2006 [5-6]. The objective of the present study was to evaluate the efficacy of the two variations of the impulse momentum approach using deflection-time response data from oblique sled tests conducted using anthropometry-specific modular load-wall and compare with outcomes from pure lateral side impact sled tests performed with non-anthropometry-specific segmented load-wall.

I. METHODS

The methods used in the study are available [7]. Briefly, a scalable and modular load-wall was designed with multiple segments to individually load the shoulder, thorax, abdomen, inferior and superior regions of the pelvis, and left lower extremity. The individual plates accommodated at least two tri-axial load cells attached to a rigid fixture to record impact forces sustained by different body regions, described above. The plates were oriented such that the intact post mortem human surrogate (PMHS) sustained the anterior oblique lateral impact. The surrogates were positioned on the sled and instrumented with two chestbands to obtain deflections. They were wrapped at the level of the xyphoid process and tenth rib [7]. Deflection contours were computed at each one-quarter millisecond from curvature signals (RBandPC, Conrad Technologies, Washington, DC). Thorax and abdomen deflection-time responses were computed at all points along the ipsilateral side of each PMHS.

Responses were normalized using impulse-momentum approaches, suggested in 1984 and 2013 [2,4]. The effective masses of body regions (applicable for both approaches) were computed based on the impulse-momentum of body region-specific forces, obtained from respective load cells attached to the modular load wall. The standard effective masses of the thorax and abdomen were obtained by normalizing with respect to the mass of the standard mid-size male [3]. Reference values used to determine length ratios were based on the breadth of the thorax and abdomen in the original impulse-momentum approach. In the more recent extension/refinement of the original impulse-momentum approach, instead of determining the stiffness ratios of the two body regions based on characteristic lengths, defined based on breadth measurements in this study, effective stiffness of each body region was computed using the force and deflection data from each test, as this set of information was gathered from load cells and chestbands [4]. Stiffness ratios were computed using the stiffness determined above. The coefficient of variation, defined as the ratio of the standard deviation to the

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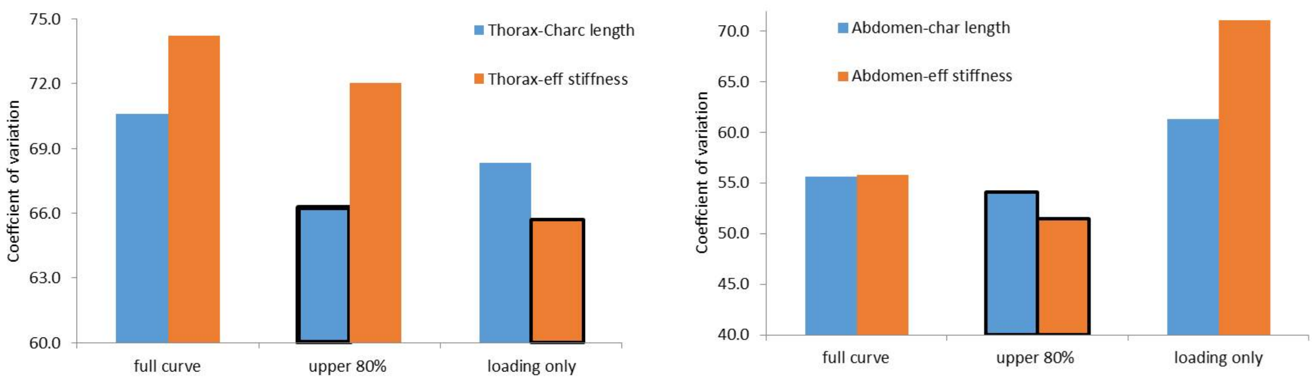
mean was computed for both body regions and for both approaches. Instead of determining this metric at the peak deflection value, it was computed based on the suggested method of using the upper 80% of the mean response curve [4]. In addition, the coefficient was computed using the full curve and only the loading phase of the response. The resulting outputs were compared for both body regions and three combinations of the coefficients.

II. INITIAL FINDINGS

Figure 1 shows the coefficients of variations determined using different regions of deflection-time responses for the thorax (left) and abdomen (right) based on the original impulse momentum method, suggested by Mertz [2] and its modification based on specimen-specific local stiffness, suggested by Moorhouse [4]. These are termed as charc length and eff stiffness respectively, in the legends of the bar charts. Note that, for the thorax, the loading portion of the curve yielded the best/lowest value of the metric using the former original approach while the coefficient of variation determined using the upper 80% of the curve was efficacious (both bars are shown as boxes in solid color) for the latter approach. In contrast, for the abdomen, the use of the upper 80% curve yielded the best value of the metric in both approaches (boxes in solid color).



III. DISCUSSION

To the best knowledge of the authors, no single study has comparatively evaluated the quantitative efficacy of impulse momentum normalization approaches in oblique side impact sled tests. While normalization factors remain the same for effective mass, they are different for stiffness: the original approach is based solely on the characteristic length [2] and the more recent approach uses the local force-deflection response [4]. The present results, while acknowledging the scientific rigor supporting the impulse momentum approach for normalizing temporal deflection data from side impact sled tests with the oblique load vector, quantification processes involving the determination of coefficients of variation appear to depend on the choice of the selection of the temporal region of the curve. The quantification processes resulted in the same outcome for the abdomen (Figure 1). However, outcomes for the thorax were dependent on the choice of the temporal region of the deflection history. As a comparison, the effective stiffness approach yielded the best outcome for deflection-time responses in two of the four initial conditions used in pure lateral side impact tests [4]. These results emphasize that outcomes of normalization techniques depend on methods used in the quantification process and in addition experiment type may also have an influence.

IV. ACKNOWLEDGMENTS

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V. REFERENCES

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