Sensitivity of the DAMAGE Injury Metric to Perturbations in Head Kinematic Signals

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I. INTRODUCTION

Head injury metrics, such as DAMAGE [1] and HIC [2], are dependent on kinematic measurements collected during automotive safety assessments and research to evaluate the potential for traumatic brain injury during crash events. Measured or simulated head kinematic time histories, such as translational acceleration and angular velocity, are typically obtained from a variety of different types of anthropomorphic test device or human body model. In practice, head kinematic measurements are subject to a variety of uncertainties and variations arising from sensor noise, filtering methods, bias errors, post-processing procedures and inherent variability in physical testing conditions. Such variability may influence the computed value of the injury metric and potentially affect the risk assessments derived from them. The degree to which perturbations in head kinematic signals affect the resulting DAMAGE value has yet to be evaluated. The objective of this study was to quantify the sensitivity of the DAMAGE metric to different signal perturbations and to characterise the inherent variability that may arise in dummy-based testing environments. To achieve this objective, a systematic signal sensitivity analysis was performed using head kinematic time histories obtained from a representative frontal crash test.

II. METHODS

A dataset representing head angular acceleration collected during a 2015 IIHS Moderate Overlap test was used in this study. This test was selected as it had one of the higher DAMAGE metrics in the group of similar tests. The data were sampled at 10 kHz, and contained 6,000 data points over 600 ms of the crash test. Using the baseline data, a systematic framework of signal perturbation was applied to evaluate the sensitivity of the DAMAGE metric to these variations in head kinematic signals. By systematically modifying the signals and recomputing DAMAGE, the sensitivity to different sources of signal variability can be quantified. A summary of the techniques used to modify the baseline signal, along with the parameter levels, is presented in Table I.

TABLE I

SUMMARY OF THE SIGNAL PERTURBATION PARAMETERS, THEIR DESCRIPTIONS, AND THE PARAMETER LEVELS USED TO PERTURB THE BASELINE HEAD KINEMATIC SIGNALS IN THE SENSITIVITY ANALYSIS

Parameter	Description	Levels
Signal-to-Noise Ratio (SNR)	Additive Gaussian noise was introduced into the signal to simulate sensor noise or measurement uncertainty [3]. Levels are in units of dB.	-5, 0, 5, 10, 20, 50
Y-axis Signal Shift	A constant offset was added to the signal amplitude to simulate sensor bias or baseline shift in measurements [4]. Levels are expressed as the percentage shifting relative to the maximum absolute amplitude.	-20%, -10%, -5%, 5%, 10%, 20%
Time Step Variation	The time step resolution of the signal was modified to simulate different sampling rates or resampling procedures in data-acquisition systems. Levels are expressed as the scale factor on sample frequency. For frequencies higher than the baseline (10,000 Hz), data were linearly interpolated.	0.01, 0.05, 0.1, 10, 20, 100
Frequency Shifting	The frequency content of the signal was altered by shifting the temporal characteristics of the motion [4]. Levels are expressed as the scale factor on the time between sample points (baseline is 0.1 ms).	0.5, 0.67, 0.9 1.1, 1.5, 2
Number of Spike Burst	Short-duration transient spikes were introduced into the signal to simulate measurement glitches or high-frequency disturbances by controlling the number and amplitude of those spikes. The amplitude of the injected spikes was a percentage of the maximum absolute amplitude.	100, 1000
Amplitude of Spike Burst		100%, 50%, 10%
Signal Polarity Variation	Signal polarity changes were applied to examine whether polarity variations in the measurements influenced the computed metric [4]. Levels are 1, 2, 3 for single polarity flip (x, y, or z), 4, 5, 6 for double polarity flip (xy, yz, or xz).	1, 2, 3, 4, 5, 6

For each level of a particular signal perturbation, a modified signal was generated using the corresponding perturbation technique, and the DAMAGE metric was recomputed using the altered signal. The resulting DAMAGE

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values were subsequently compared with the baseline DAMAGE value obtained from the original signal to quantify the sensitivity of the metric to that specific perturbation. This procedure was repeated independently for each signal manipulation parameter to evaluate their individual influence on the computed DAMAGE metric.

III. INITIAL FINDINGS

The computed DAMAGE value for the baseline signal was 0.235. Subsequent perturbations were applied to this signal, and the relative change in DAMAGE was computed (Fig. 1). The horizontal axis represents the different levels of each parameter considered in the study, while the vertical axis shows the corresponding percentage change in the DAMAGE value relative to the baseline signal.

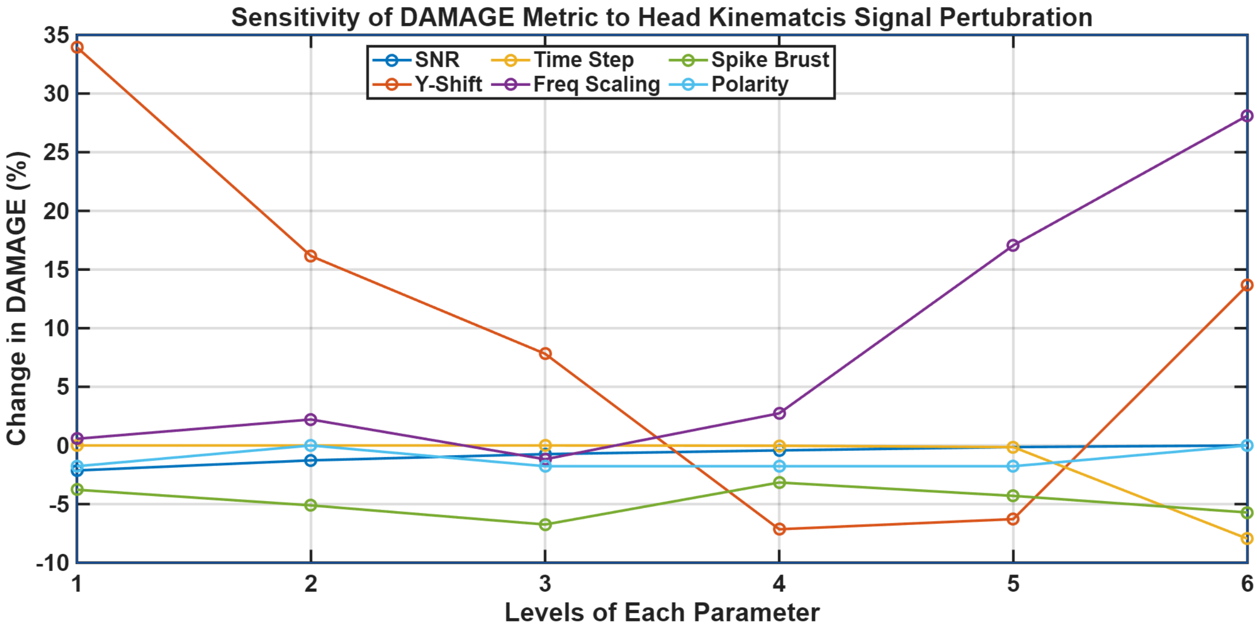

Fig. 1. Percentage change in the computed DAMAGE metric relative to the baseline value as a function of the applied signal perturbation parameter level.

In general, the DAMAGE metric was not sensitive to most of the signal perturbations applied in this study, where results were less than 5% difference in metric compared to the baseline DAMAGE value. The Y-axis shifting of angular acceleration showed the largest influence on the computed DAMAGE metric, where shifted values greater than +/- 5% of the signal magnitude would result in substantial differences in the DAMAGE metric. Increases in the time sample period above 1.5x, representing a similar decrease in the frequency of the data, resulted in noticeable increases in DAMAGE value.

IV. DISCUSSION

This study evaluated the sensitivity of the DAMAGE injury metric to controlled perturbations in head kinematic signals. The results demonstrate that the metric is generally insensitive to most signal perturbations, but two noticeable cases were identified. Substantial systematic biases (y-axis shift) in head acceleration (more than 5% of the amplitude) will have noticeable effect on the calculated DAMAGE value. Since the standard post-processing approach is to remove initial signal offset before analysis, this type of perturbation is unlikely to impact the use of DAMAGE in practice. More interesting is the finding that decreasing the frequency of the head kinematic content increased the DAMAGE metric for this example case; DAMAGE is a 2nd order system and acts similarly to a low-pass filter. More investigation into the frequency content of head acceleration data is needed since head kinematics and frequency content are both influenced by dummy biofidelity and restraint design. Overall, this study provides insight into the robustness of the DAMAGE metric and helps to inform best practices for signal acquisition and processing in injury biomechanics studies. Future directions will expand analysis beyond a single frontal crash case and investigate the effects of combined perturbation scenarios.

V. REFERENCES

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