Identifying Critical Head Impact Time Window using a Pre-trained Neural Network: an Initial Study

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I. INTRODUCTION

Head impact sensors such as mouthguards are becoming widely deployed to record head impact kinematics in various contact sports. Their six-degree-of-freedom (6-DOF) time-varying impact kinematics allow using a head injury model to simulate the physical impact. Model simulated brain strains are generally believed to be more effective than impact kinematics for injury prediction [1]. While studies have suggested that different mouthguards are similarly accurate in measuring peak kinematics, they do not provide the same time window for the recorded impact kinematics [2]. Some record 50 ms of impact while others record 100 ms or up to 200 ms. Given that the recorded impact kinematics serve as input to the head injury model, there is a need to investigate whether the recorded data are sufficient to ensure accurate model-based impact simulation.

In this study, we iteratively reduce the impact temporal window and investigate whether the resulting brain strains maintain the same relative to the baseline using a pre-trained convolutional neural network (CNN) model [3]. This model allows instant estimation of spatially detailed brain strains with sufficient accuracy as compared to the directly simulated counterparts. This avoids time-consuming direct impact simulations.

II. METHODS

Due to the lack of a large dataset of real-world impacts with a long time window, e.g., >= 100 ms, we resorted to an impact emulator [4] to generate 2000 head impacts (100 ms duration, temporal resolution of 1 ms) for analysis. This emulator utilises modal characteristics of real-world impacts to randomly reconstruct impacts using truncated principal components. The impact kinematics were then pre-processed following an established protocol [3] before inputting to the CNN model. Specifically, the rotational velocity and acceleration profiles were first synchronously re-positioned so that the resultant rotational velocity peak occurred at the fixed time point of 100 ms. Both ends of the velocity/acceleration profiles were next replicated (zero acceleration) so that to maintain a total length of 200 ms. Finally, the rotational acceleration magnitude was scaled to 1% before concatenating with the velocity profiles to generate a 6-by-201 image for CNN input.

To test the applicability of the CNN for the emulated impacts, 10 randomly selected profiles were simulated using the anisotropic Worcester Head Injury Model (WHIM V1.0) [5]. The CNN-estimated maximum principal strains (MPS) were similar to the directly simulated (elementwise regression slope, k, of 0.85–1.0, with Pearson correlation coefficient, $r>0.85$). The CNN-estimated brain strains for the 2000 impacts served as the baseline.

To determine the sufficient time window of impact profiles, we systematically truncated the profiles either before or after the resultant rotational velocity peak for up to 40 ms at a step size of 10 ms. This process is graphically illustrated in Figure 1. For each truncated impact, we then used the CNN to estimate elementwise MPS. The resulting k and r relative to the corresponding baseline strains were used to assess the significance of profile truncation on the resulting brain strains.

III. RESULTS

Figure 2 compiles the k-r relationships for each of the profile truncation experiments. We considered that a truncated profile led to comparable elementwise MPS relative to the baseline when both k and r did not deviate from the value of 1.0 (when the two were identical) by more than 0.1. The percentage of the profiles that satisfied the criteria was referred to as the *success rate* (SR). The results indicate that at least 40 ms prior to the resultant velocity peak and at least 20 ms after the peak were necessary to retain an SR>0.9 (Figure 2 lower

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right shows the SR for impacts with the minimum of 60 ms time window).

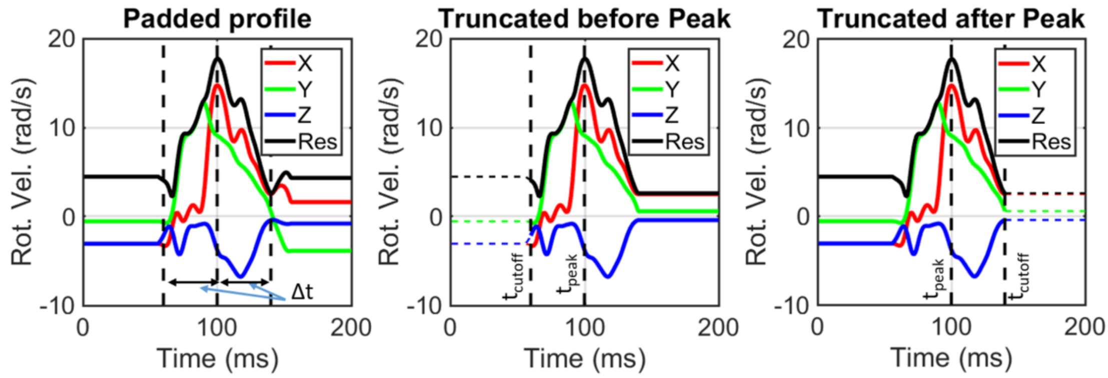

Fig. 1. Illustration of the impact profile truncation process. (a) baseline; (b) truncated before the resultant peak; and (c) truncated after the resultant peak.

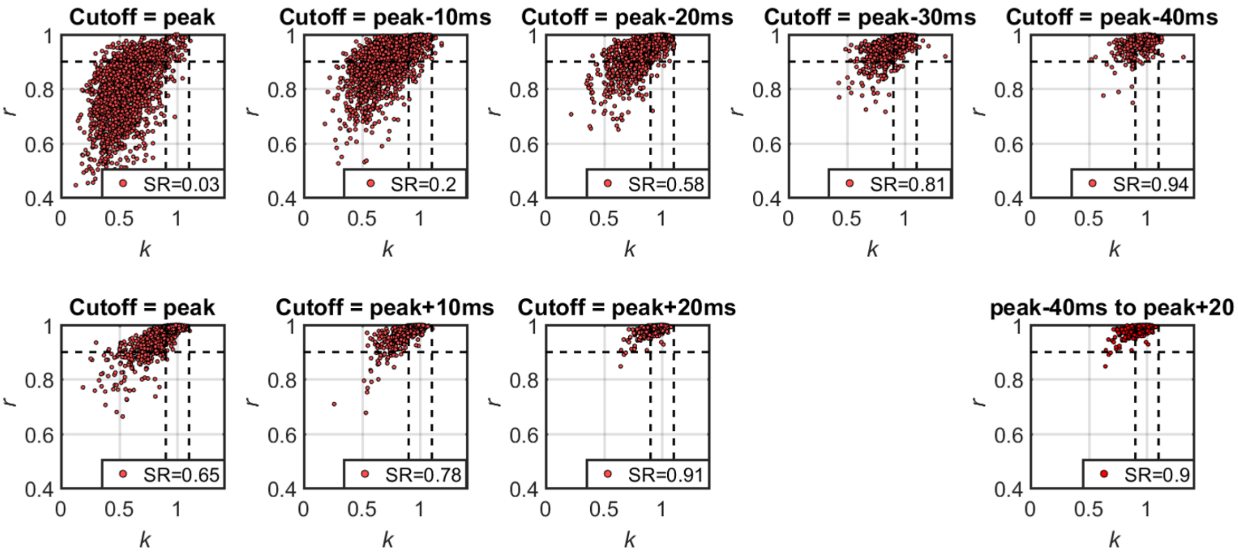

Fig. 2. *k-r* comparisons between responses from truncated profiles and those from baseline. Top row shows results truncating before the peak; bottom left three show results truncating after the peak. Bottom right shows an "acceptable" time window that yields sufficiently accurate responses with SR>0.9. SR: success rate.

IV. DISCUSSION

The complete head impact kinematic temporal profiles are necessary for model-based impact simulation. Therefore, they need to be *accurate* in terms of the actual kinematic profile shape beyond simple peak magnitudes to ensure faithful simulation of the physical impact. Naturally, the accuracy of the recorded event would improve with more complete capture and higher temporal resolution; but this could also pose challenges in practice due to hardware limitations. This study aims at providing some initial insight into the minimum time window necessary to retain sufficient model-based impact simulation accuracy. Based on 2000 emulated impacts, we show that at least 40 ms prior to and 20 after the resultant peak velocity (total of 60 ms) may be necessary to preserve sufficient accuracy for spatially detailed strain. In the future, we will apply the technique to a large, actual real-world impact dataset (vs. emulated here) to further confirm. We will also evaluate the utility of the CNN model more rigorously. Nevertheless, this study does suggest that the CNN model has the potential to bypass typically time-consuming impact simulations to facilitate *big data* analysis in the future.

V. REFERENCES

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