Challenges in the Validation of Active Human Body Models against Averaged Volunteer Data

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I. INTRODUCTION

In the last decade, Active Human Body Models (AHBMs) have been developed to react to low accelerations, such as those occurring during pre-crash manoeuvres, by exerting active forces based on the level of muscle activation. These models have been validated against volunteer test data, most commonly comparing against volunteers' average excursions and the corresponding one-standard-deviation corridor [1]. However, it should be noted that significant variations exist not only between individual responses but also within volunteers themselves, depending on factors such as their muscular state [2-4]. Consequently, the average curves tend to deviate from the responses of those volunteers exhibiting the largest and the smallest excursions. However, predicting the most and least forward or lateral postures of the occupants may be more relevant to assessing their engagement with the safety system in the event of a collision, which could lead to different injury risks [5].

The Correlation and Analysis tool (CORA) [6] has been extensively applied in the field of impact biomechanics [7] to objectively evaluate the behaviour of surrogate tools, such as physical and numerical dummies as well as HBMs. Following this approach, the tool has been utilised to evaluate and rate the performance of AHBMs [1][8].

In this study, a CORA rating analysis was performed to evaluate the lateral head kinematics of a cohort of 10 volunteers under the same loading conditions by comparing each volunteer's behaviour to that of the other nine volunteers. The aim of this study is to demonstrate that if an AHBM is capable of representing the response of the volunteers exhibiting the largest and the smallest excursions, it would be rated as fair or poor when objectively evaluating its performance against the average volunteers' response, although it would correctly fulfil its intended purpose.

II. METHODS

Experimental Testing

Lateral head excursion data from 10 volunteers in a sled experiment by Sandoz *et al.* [3] were used as an example validation dataset in this study. The volunteers had an anthropometry comparable to the 50th percentile American male (176.5±3 cm, 75.8±3 kg). They were seated on a sled and were subjected to four different lateral pulses. Specifically, the data from the first *plateau high* pulse (see experimental matrix in [3]) were considered, which corresponds to the fifth trial in each volunteer experiment. The *plateau high* pulse is characterised by a symmetrical acceleration and deceleration plateau of maximum 0.3 g for a total duration of 2 s.

CORA rating

Each volunteer's head lateral excursion was objectively compared to the excursion of the other nine volunteers using the CORA tool. In this study, the default CORA settings were used. This means that the corridor and cross-correlation method were weighted equally, with 50% of the total rating score. Specifically, the weights for the cross-correlation method were divided into 40% for curve size, 40% for curve shift and 20% for curve shape. The CORA scores below 0.58 were defined as poor matches, between 0.58 and below 0.8 as fair, between 0.8 and 0.94 as good, and above 0.94 as excellent, comparable to ISO/TS 18571. The time interval of interest for the CORA rating has been defined from 0 s to 1.5 s, corresponding to the initial lateral head movement.

III. INITIAL FINDINGS

The maximum head lateral excursion varied significantly among the volunteer cohort (Fig. 1). The maximum head excursion ranges from 100 mm to 377 mm for volunteers 1 and 3, respectively. The maximum of the average

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head lateral excursion is 237 mm, with a one-standard-deviation of ±99 mm. The kinematic curves of volunteers 1, 2, 3 and 9 fall partially outside the one-standard-deviation corridor.

Furthermore, it is observed that those volunteers showing larger lateral head excursions than the average exhibit a steady increase of the lateral head excursion until they reach the maximum. In contrast, those volunteers experiencing less lateral excursions, maintain their head position at their maximum excursion over about 0.5 s.

The CORA ratings for each volunteer are shown in Fig. 2. It is worth noting that none of the volunteers reached an excellent rating. In particular, three volunteers received a poor rating. The poor rating was obtained for volunteers 1, 3 and 9, who were identified as the volunteers showing the least and most lateral excursions, respectively.

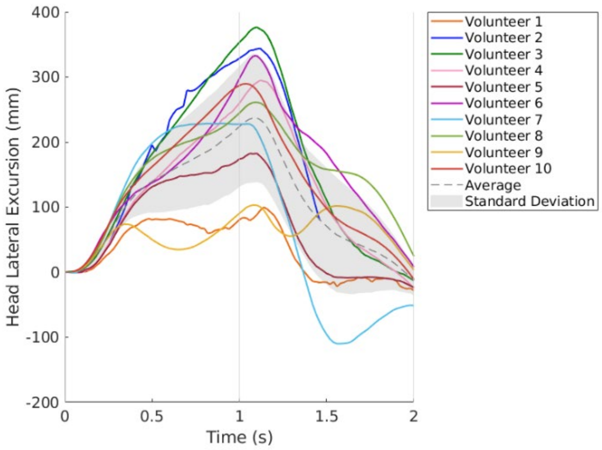

Fig. 1. Head lateral excursion of 10 volunteers subjected to a 0.3 g pure lateral pulse (acceleration 0–1 s, deceleration 1–2 s, sled stop at 2 s).

Volunteer	CORA Rating: Corridor method	CORA Rating: Cross-correlation method	CORA Rating: Total
1	0.27	0.56	0.41
2	0.39	0.78	0.59
3	0.37	0.75	0.56
4	0.84	0.81	0.82
5	0.67	0.80	0.73
6	0.70	0.77	0.73
7	0.68	0.66	0.67
8	0.92	0.91	0.91
9	0.25	0.62	0.44
10	0.83	0.88	0.85

Fig. 2. CORA ratings for each volunteer. The cells shaded in orange, yellow, and green have a poor, fair and good rating, respectively.

IV. DISCUSSION

Typically, the validation of AHBMs is assessed by using objective rating approaches (e.g. CORA) against the average data of volunteers [1][8]. Nonetheless, it has been extensively demonstrated that there is a large inter- and intraindividual variation in volunteer kinematics [2-4]. This variation is not represented by AHBMs validated only against average data. In the experimental data presented in this study, the maximum head lateral excursion shows a spread of 277 mm for 10 male volunteers with very similar anthropometry.

If an AHBM was to replicate the behaviour of the volunteers exhibiting the largest and the smallest excursions, i.e. volunteers 3 and 9, the CORA rating would score the AHBM's response as poor. On the other hand, an AHBM reproducing the head kinematics of volunteer 8 would receive the highest rating of 0.91, since it would predict the closest excursion curve to the average curve among all the considered volunteers. However, it can be observed that the average excursion curve is an artificial curve that does not match completely with any of the volunteers' responses. It is therefore proposed that future studies explore alternative rating methods, with the aim of overcoming the challenges identified in this study. Such methods might include dividing the corridor into sub-corridors to represent the different volunteer response types, or rating the models against individual curves.

Furthermore, numerical studies performed considering different levels of muscle activation during a pre-crash phase have indicated that muscle activation significantly affects the posture prior to the in-crash phase [5]. In turn, the occupant posture will affect the interaction with the safety systems, which may lead to a difference in the injury risk [5]. Therefore, it is important that AHBMs do not only represent the average response, but also the relaxed and tensed behaviours, since considerable effects might otherwise be overlooked.

V. REFERENCES

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