Modeling Trajectories of Human Volunteers in Low-Speed Frontal Impacts Using Bezier Curves

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ABSTRACT

Head injuries are the most common serious injury sustained by children in car crashes. Biofidelic anthropomorphic test devices (ATDs) improve injury prevention by evaluating the effectiveness of motor vehicle safety systems. Due to a lack of pediatric validation data, pediatric ATDS have been size-scaled from adult data. However, studies have shown that child subjects experience different motion relative to adults that are not simply scaled down by size. These results call for a better understanding of the differences and for a more biofidelic ATD to evaluate child injury prevention. Previous studies have noted age-based differences in maximum excursions, even after accounting for differences in size. However, to our knowledge, no study has quantified the effects of age on trajectory shape. The objective of this study was to use a functional modeling approach to quantitatively evaluate the factors that influence landmark trajectory shape. Low speed (<4 g) frontal sled tests were conducted on 30 human volunteers from ages 6 to 30 years. Subjects were restrained by a lap and shoulder belt. Photo-reflective markers were placed on anatomical landmarks of interest, such as the head top, and quantified by a 3-D near infrared tracking system. Subjects received six repetitive trials. Head top landmark trajectories in the sagittal plane were modeled using a 4^{th} order Bezier curve equation:

$B(t) = (1-t)^4P_0 + (1-t)^3tP1 + (1-t)^2t^2P_2 + (1-t)t^3P_3 + t^4P_4$

Where P_i are control points (X, Z) that determine the shape of the curve and t [0,1] represents the relative location of the current point along the trajectory. Control points were fit using an iterative least-squares algorithm. The trajectory was fit from time zero (start of acceleration) to the point at which the landmark had rebounded 20% from the point of maximum excursion. For the current analyses, the control points were normalized by translating the first control point to the origin. A principal component analysis was used to express the control point vector as readily interpretable shape variables. The first four components accounted for 98% of the variance. A linear regression analysis found that the first four principal components were significantly related to subject erect sitting height ($p<0.001$) and other correlated measures of body size. Using the resulting regression model, shorter sitting height was associated with greater head excursion and a more rounded trajectory, indicating greater neck flexion. To our knowledge, this represents the first application of these functional shape analysis methods to biomechanics trajectory data. The method provides a concise, effective quantification of trajectories that will be useful for specifying and evaluating ATD performance. Future work will extend the method to multiple trajectories.