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Quantifying helmet fit: A comparison of helmet fit in collegiate football players and anthropomorphic test dummies

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ABSTRACT

Introduction: Helmets are an essential piece of equipment in football, which generally cushion the impact force to the head and spread the force over a large area. Helmet fit aims to achieve these design goals by providing protection and comfort, but variability in head shape and size between players makes it difficult to achieve a proper fit. Furthermore, the relationship between fit and comfort has yet to be investigated, as well as how head shape and size variation affects overall helmet fit. In addition, the degree to which helmets provide head protection are based on laboratory impact testing standards using helmets that are fit to anthropomorphic test dummy (ATD) headforms. The purpose of this study was to investigate the relationship between pressure at the head-to-helmet and chin-to-chin cup interfaces and players' subjective ratings of fit and comfort, while also obtaining information on head shape and size variation among football players. Further, pressures at these interfaces as well as head surface geometry were compared to those on ATD headforms to provide insight on how laboratory impact testing conditions can be improved to make helmet fit and the subsequent impact response more realistic.

Methods: Anthropometric head measurements were obtained, and 3D head models were generated using a portable 3D scanner. Head-to-helmet interface pressure was quantified using miniature force sensors integrated into the padding interface of a football helmet model, and chin-to-chin cup pressure (P_{CHIN}) was estimated using custom webbing-sensitive load cells that quantified chin strap tension. These pressures were examined at increasing tightness increments along the chin straps. Tightness of fit was defined by P_{AVG} and P_{MAX}, which represented the average pressure across all sensors and maximum pressure at any location on the head, respectively. Pressure in each cranial region (frontal, temporal, parietal, occipital) was also estimated. Uniformity of fit was defined by the Average Fit Index (AFI) score, which represented the ratio between P_{AVG} and P_{MAX}. Subjective ratings of fit and comfort were obtained while the helmet was donned, using 5-point Likert scales (i.e. loose – tight, comfortable – uncomfortable). Estimates of comfort thresholds for P_{MAX} and P_{CHIN} were established based on differences in pressure quartiles between comfortable and uncomfortable helmet ratings. A "best fit" condition was determined for the NOCSAE and Hybrid III 50th percentile adult male headforms, wherein tightness (P_{MAX}, P_{AVG}, P_{CHIN}) and uniformity (AFI) of fit were computed for comparison to human participants.

Results: Anthropometric head measurements in participants were comparable to the population mean. Comfort thresholds for P_{MAX} and P_{CHIN} were 14 kPa and 5 kPa, respectively. Mean pressure was highest in the occipital region. Mean AFI score when participants rated the helmet to be comfortable and uncomfortable were 0.42 ± 0.31 and 0.39 ± 0.33, respectively. Regarding the ATD headforms, mean pressure was also highest in the occipital region. Mean AFI scores were 0.44 ± 0.31 and 0.55 ± 0.27 for the NOCSAE and Hybrid III headforms, respectively. P_{AVG} was highest on the NOCSAE headform (7.85 kPa), while the Hybrid III headform (6.30 kPa) and human participants (6.78 kPa) exhibited lower pressures. Participants had larger heads on average than both ATD headforms, with the biggest differences being in the parietal region.

Conclusions: Head-to-helmet and chin-to-chin cup interface pressure was higher when participants rated the helmet to be uncomfortable, and a comfort threshold for both interface pressures was established. AFI scores did not substantially improve when the helmet was tightened or when it was rated to be comfortable, suggesting that comfort may not have to be sacrificed for protection, since tightening the helmet may not improve uniformity and its ability to spread the impact load over a larger area. The

surface geometry comparison between the ATD headforms and human heads shows that more improvements can be made to increase their biofidelity, which will also improve the biofidelity of the impact response. Future research can incorporate the objective and subjective methods used in this study using a sensor application that can be integrated into multiple helmet models, and impact testing with ATD headforms can also be conducted with the estimated fit and comfort conditions obtained from this study to investigate how these affect the impact response.