

Strength at Impact Testing of Customized 3D Printed Guards

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The purpose of this study was to investigate the strength at impact of customized, 3D-printed guards for members of Auburn University's football team. The potential benefits of these guards are numerous, ranging from an increase in mobility due to the thin design (3 mm), to greater protection because of extreme customization that follows complex contours of the body.

The 3D printed guards were developed by first obtaining a 3D scan of the shoulder on a Body Opponent Bag (BOB)[®]. This scan was then used to create a virtual model of the negative of BOB's shoulder. The negative was 3D printed as a mold, which was filled with concrete to generate a replica of BOB's shoulder. Eight-millimeter-thick Shockshield[®] was overlaid on the concrete shoulder to replicate soft tissue. The shoulder scan was also used to generate a virtual model of multiple shoulder guards for testing. Three shoulder guards were modeled and printed: (1) a 3mm-thick guard with no offset and no padding, (2) a 3mm-thick guard with no offset and no padding and with the printer interrupted for 24 hours halfway through the print, and (3) a 3mm guard with a 3mm offset and 3mm-thick Ethylene-vinyl acetate (EVA) padding. All 3D printing was performed on a Raise 3D Pro2 printer using polylactic acid (PLA) as the material. A drop tower was also built to allow for a controlled helmet drop of approximately six feet, directly onto the guards. Each guard was placed on the concrete mold of the shoulder underneath the drop tower and was struck by a football helmet with added mass to total 9 kg. We hypothesized that for each guard design, the guard would not break after the first strike, but would break on or before the tenth strike. During each trial, a Vicon[®] motion capture system was used to record the velocity of the helmet through impact and two AMTI[®] force plates were used to record the impact force.

The results of this study provided valuable information on the strength of the 3D printed guards. Table 1 shows the force (N), momentum (kg-m/s), and the trial number in which the guard broke for each of the three guard

designs. A fourth condition was added to testing after the third guard, a 3mm guard with 3mm-thick EVA padding, did not break during any of the ten impacts. For this fourth condition, the total helmet mass was increased to 10.8 kg. This increase in mass increased the momentum to 57.46 kg-m/s, higher than the estimated average NFL linebacker's head and helmet during a full-speed tackle [1].

The results of the initial three testing conditions demonstrated the durability of the guards. The additional fourth testing condition provided useful information on the strength limit of the guard. Notably, the helmet used for testing also broke on the same 17th strike. Overall, the testing conditions were determined to be more extreme than any hit experienced during a football game. This is because although momentum of the impact was matched, the guards were placed on a concrete shoulder that was set against an immovable surface, the ground. The high strength of the guards determined from this study indicates a good potential for use in sports.

Statement of Research Advisor

Grace contributed to this project by designing and building the test platform. She also conducted all of the impact testing, processed data, and aggregated the results.

—Michael Zabala, Mechanical Engineering

References

- [1]. N. Yoganandan, F.A. Pintar, J. Zhang, J.L. Baisden. *Physical properties of the human head: mass, center of gravity and moment of inertia.* J Biomech, 42 (9) (2009), pp. 1177-1192.

Table 1: Impact Testing Results. *Indicates that this guard was impacted 10 times with a total helmet mass of 9 kg, then impacted seven more times with a helmet mass of 10.8 kg until a break occurred. On the 17th impact both the guard and the helmet broke.

	Force (N)	Momentum (kg m/s)	Break Impact Number
3mm (no padding)	1656.72	46.63	NO BREAK
3mm interrupted (no padding)	2029.39	47.53	10
3mm with 3mm EVA foam	1749.23	47.53	NO BREAK
3mm with 3mm EVA foam (additional testing with larger helmet mass)	2036.65	57.46	17*

Appendix

Estimates

95th% male head: 5.377 kg (11.85 lb) head mass [1]

Assumed impact velocity of a tackle: 25.2 fps (7.7 m/s, 17.2 mph)

Momentum of head and helmet at impact: 5.377 kg*7.7 m/s = 41.4 kg m/s