Neck Loading Due to Head Immersion In Water at High Speeds

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Medical literature and accident databases report soft tissue injuries to individuals engaged in various water sports. These activities have included water skiing, power boat racing, high speed boats, personal watercraft, water slides, and high diving. When a body strikes the water, surface impact and hydrodynamic forces may under some circumstances of higher speeds cause injury. In boating this phenomenon may occur if the boat occupant becomes separated from the boat and enters the water at high speed.

Neck loading due to head immersion in water at high speeds produces drag forces which will be transmitted through the neck and cervical spine. To better understand this phenomenon a test program was designed to study the effects of neck loading with and without a helmet. Using an instrumented Hybrid III ATD and 50% head form, physical testing of neck extension moments and shear forces was performed. With a specially designed test apparatus mounted on a boat, testing was done at various speeds to examine the loads applied to the neck.

The analytical method allows extrapolation of slower speed empirical test results to loads which may occur during high speed immersions. Neck injury mechanisms and immersion injury threshold velocities are presented based on the study. In addition to testing just a bare head, tests were performed in which a bare head was fitted with a full face helmet and comparison data were measured.

The body position simulated in the test sequence represents a severe water entry position. The test head form was placed upside down and facing forward into the oncoming water flow. In this position shear forces and extension moments on the upper and lower neck were measured. As expected, the forces and moments increase with increased speed and bigger helmets. The water entry concept modeled was such that if a person falls in the water head first, for a brief time only the head will be immersed with the rest of the body still traveling forward until the ever increasing drag on the head and neck become great enough to slow, tumble, and rotate the body. The dynamics of the whole body entry dropping into the water were not evaluated in this testing. However, we believe that the greatest neck loads will occur in this idealized water entry position in which only the head is immersed. Once the immersion is deep enough that the shoulders and upper torso penetrate, then the neck loads and extension moments will decrease.

The test procedure involved the design and development of a stable platform to hold the head in position, provide constant velocity, immerse the head, and measure the response. Interesting design issues included waterproofing the Hybrid III neck and transducers and providing a stable platform for towing. We developed a planing catamaran fixture that was hinged and isolated from a large power boat. A stable vertical reference to the water surface was achieved with proper design and testing of the planing catamaran hulls. A fixture supporting the head form was extended to near the front of the area between the catamaran hulls, therefore, the head was being pushed through the undisturbed flat water in front of the boat. Speeds of 30 mph were obtained with this test fixture and boat combination.

Data were digitally sampled at 1000 hertz for head depth of immersion of 12.4 inches from when the bare head or helmeted head first entered the water. Two summary figures are shown below of selected test data. Regression analysis was used to pass exponential curves through the measured data points. In all cases the helmet increased the drag or shear force on the cervical spine. For the full face helmet the drag force on the lower neck increased 40% at 30 mph. Similarly, the upper neck extension moment increased 160 % at 30 mph for the full face helmet compared to the bare head.

Physical understanding of hydrodynamic forces on objects moving through the water has shown that forces are functions of the shape of the object, the size of the object, and the relative speed between the object and the water. Larger, less hydrodynamically streamlined objects typically will have more drag than smaller, more streamline shapes. This physical behavior is demonstrated in the results of our tests and has been quantified for the bare head shape compared to a head with full face helmet.