INTRODUCTION
Motorcycle helmets can reduce the severity of head and brain injuries by decreasing the level of force and acceleration imposed on the rider’s head. Despite this fact, helmets have limitations with respect to their ability to mitigate all potential brain injuries. Brain injuries occur when there are sufficient magnitudes of acceleration inflicted on the brain. Translational acceleration causes focal brain injuries whereas rotational acceleration causes both focal and diffuse injuries [1]. Focal injuries, such as contusions or hematomas, are lesions where the damage is locally defined [1]. Diffuse injuries are those injuries with axonal, neural, and microvascular effects and brain swelling [1]. Current helmet verification test standards only measure translational accelerations, yet rotational accelerations are known to cause more severe injuries [2]. Data from the Department of Transportation (DOT) helmet verification tests were examined in this study to determine the effectiveness of a motorcycle helmet in preventing rotational brain injuries [3]. The inclusion of rotational acceleration measurement could result in higher standards for helmet design that, if executed, could provide the rider better protection against both rotational and translational acceleration brain injuries.

METHODS
A collection of frontal impact headform translational acceleration data points for the subject study were obtained through Federal Motor Vehicle Safety Standards (FMVSS) 218 compliance testing reports from 2003 to 2011. The translational acceleration data were separated into three helmet configurations: complete facial, full, and partial. The data were separated in order to determine whether a difference exists in the acceleration data based upon the type of helmet configuration. The difference in the translational data compiled between DOT approved helmets and novelty (non-DOT approved) helmets were also examined. In addition, data were separated based upon differences in the shell material (Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC) and fiberglass) used in matching helmet configurations with similar foam liner material in order to characterize shell attenuation properties. Finally, data were separated by differences in foam type (Expanded Polystyrene (EPS) and Polystyrene (PS)) to observe the influence of foam properties. The effectiveness of the various motorcycle helmet characteristics were analyzed using the Head Injury Criteria (HIC) and Abbreviated Injury Scale (AIS). The subject study sought to determine the effectiveness of selected motorcycle helmets in the prevention of rotational acceleration brain injuries.

RESULTS
The average frontal impact headform translational acceleration experienced for 143 DOT motorcycle helmets was 111 g. The complete facial, full, and partial helmet’s average headform acceleration was 108 g, 111 g, and 114 g, respectively. Fiberglass shell material had the highest headform acceleration at 124 g, while the lowest headform acceleration was obtained by shell material made of ABS (94 g). In comparison, EPS foam average headform acceleration was 106 g whereas PS foam had an average headform acceleration of 112 g. Our data of partial style novelty helmets indicated that headform accelerations were approximately double the partial headform accelerations of the DOT approved helmets consistent with Scher et. al. [4]. Since the rotational accelerations are derived from the translational accelerations, they followed the same relationship.

DISCUSSION AND CONCLUSIONS
The average helmet translational acceleration of 111 g corresponds to an HIC score of 496, which falls below the National Highway Traffic Safety Administration (NHTSA) HIC14 maximum allowable value of 700 [5]; however, is associated with a mild concussion on the AIS. In contrast, the average calculated rotational acceleration was 9837 rad/s² resulting in an HIC score of 1317. This HIC value is well above the maximum allowable threshold and corresponds with the AIS measure indicating a severe concussion will occur.

Motorcycle helmets can reduce the severity of head and brain injuries but have limitations with respect to their ability to mitigate all potential brain injuries. Current helmet design emphasizes the evaluation of translational acceleration; nonetheless it is known that rotational acceleration can produce more severe focal and diffuse brain injuries [2]. In real life accidents, a combination of both translational and rotational acceleration is the most common mechanism for causing brain injury [7]. Our study revealed that although a helmet may meet the FMVSS 218 standard, the helmet may not prevent significant rotational acceleration brain injuries. As a result, it is our belief that considering the measure of rotational acceleration into the FMVSS 218 compliance testing may ultimately reduce the overall severity of rider brain injuries. Furthermore, it is our opinion that implementing the measurement of rotational acceleration would result in higher standards for helmet design.

REFERENCES