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Factors affecting pelvic and thoracic forces in near-side impact crashes: a study of US-NCAP, NASS, and CIREN data

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Abstract

The goal of this study was to identify variables related to vehicle design which are associated with pelvic and thoracic accelerations as measured by the driver's (near side) crash dummy during new car assessment program (NCAP) testing of motor vehicles. Vehicle specific parameters were analyzed using NCAP side impact test results. Data from national automotive sampling system, crashworthiness data system (NASS–CDS) and crash injury research and engineering network (CIREN) (both National Highway Traffic Safety Administration (NHTSA) injury databases) were assessed to confirm NCAP test observations. In addition, door armrest stiffness measurements were performed using a mechanical tester on a sample of 40 vehicles. NCAP data showed that of 10 variables tested using multiple linear regression, vehicle weight and door crush correlated with pelvic acceleration of the driver's crash dummy (overall, $r^2 = 0.58$, $p = 0.002$, $n = 165$). For thoracic trauma index (TTI) vehicle weight and peak door velocity correlated, significantly (overall, $r^2 = 0.41$, $p = 0.03$, $n = 165$). Mean TTI was 63.7 g with no side airbag ($n = 108$) and 55.6 g with a thoracic side airbag ($n = 54$), $p = 0.01$. The mean vehicle weight and door crush between airbag and no airbag groups were not significantly different. NASS–CDS data demonstrated a direct relationship between increased door crush and increased abbreviated injury score (AIS). CIREN data showed that occupants who sustained pelvic injuries had a median AIS of 3 with 24.9 cm of door crush, with abdominal injuries, a median AIS of 3 and 30 cm of crush, and with thoracic injuries, a median AIS of 4 and 34 cm of door crush. In addition, the frequency of bilateral pelvic injuries was significantly higher for subjects in CIREN crashes who were in a vehicle with a center console, but only if door intrusion was greater than 15 cm. This information may be useful in design of vehicles with greater protection in side impact crashes.

Keywords: Auto crashes; Side impact; Pelvic injury; Thoracic injury; Biomechanics

1. Introduction

In order to reduce the potential for injury during a crash, the mechanism of occupant injury and the factors affecting injury potential must be understood. The chest and pelvis are the most likely regions of the body to be injured in side impacts (Samaha and Elliott, 2003), and are probably the result of a limited stroke punch crush of the door, as described by Lau et al. (1991) and Chung et al. (1999). Samaha and Elliott (2003) confirmed, from NASS data, that the predominant injurious contact in pelvic and chest injuries is the side interior surface, specifically the door.

A number of external factors affect occupant injury potential in actual near-side collisions, including the speed and angle of the striking vehicle, its mass in relation to that of the struck vehicle, and the stiffness of its front end structure (Terrell et al., 2003). The location of impact on the door in relation to the side impact beam within the door of the struck vehicle also affects the amount of crush into the occupant space (Terrell et al., 2003; Dakin et al., 2003). Occupant variables include the gender, stature (Samaha and Elliott, 2003) and age of the occupant (Austin and Faigin, 2003).

Since the mechanism of pelvic and chest injury to the near-side occupant is due to door contact, the extent of crush

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of the door is likely to be an important variable. Also, the shape and stiffness of protrusions on the inner door panel would seem to have a direct influence on the potential for injury. Rouhana and Kroell (1989) concluded that "loading surface discontinuities can cause significant injury and that in the design of side doors and interiors, consideration should be given to the location of . . . surface protuberances such as armrests." Viano (1991), Daniel et al. (1995), Cavanaugh et al. (1996), Trella et al. (1991) and Deng and Tzeng (1996) all addressed the effects of door surface geometry on occupant contact forces. A thoracic airbag modifies the surface that the occupant contacts so it should influence occupant forces during side impact.

In order to address the possible roles of these design specific variables, we studied the results of New Car Assessment Program (US-NCAP) side impact test data, as mandated by federal motor vehicle safety standard (FMVSS) 214 related to side impact protection. In US-NCAP testing, injury potential to the chest is measured by the peak thoracic trauma index (TTI), which is computed from the average of dummy rib and lower spinal accelerations, and pelvic injury by peak pelvic acceleration. The relationship of the probability of severe chest injury to TTI is published on the NHTSA website (www.nhtsa.gov). For example a TTI value of 123, in the crash dummy, is equivalent to a 50% probability of chest injury. Since, NCAP testing controls for many crash factors such as angle, weight, speed, and stiffness of the bullet vehicle, using a moving deformable barrier, the results allow focus on specific design features of current vehicles, within the limitations of the test and dummy measurements. The goal of this study was to determine how a number of vehicle design parameters affected peak driver dummy accelerations during a near-side impact. These data were augmented by real-world crash data from both NASS–CDS (www.nrd.nhtsa.dot.gov/departments/nrd.30/ncsa/nass.html) and CIREN (NHTSA, 2003). Identification of vehicle design factors affecting dummy contact accelerations might provide insight into how to further protect against these injuries.

2. Methods

2.1. Definition of terms

The following terms and abbreviations used in the manuscript are summarized in this section:

- AIS, abbreviated injury score: numerical categorization of injuries developed by the association for the advancement of automotive medicine.
- NASS, National Automotive Sampling System: a statistical sample of crashes in the US taken yearly and used in a crash injury research database.
- NCAP and SINCAP, Side Impact New Car Assessment Program: standardized side impact crash tests mandated by federal motor vehicle safety standard 214, consisting of a stationary vehicle impacted by a moving deformable barrier of 1300 kg weight with a crushable front end representing the hood and bumper of a passenger car, approaching at a 27° angle at about 62 kph.
- CIREN, the Crash Injury Research and Engineering Network: a NHTSA funded group of trauma center based investigation teams who assess patient injuries, crash scene, vehicle damage, interior contact points, restraint use and biomechanics of injury, as described in detail below.
- SID, DOT-SID: US Department of Transportation Side Impact Dummy, designed for side impact testing.
- TTI, thoracic trauma index: a measure of the potential for chest injury. This criterion is defined from the average of rib (either T4 or T8) and spine, T12, accelerations, measured by the dummy.
- T12y: dummy acceleration measured at the T12 spinal vertebral level, in the *Y* or lateral direction, where *Y* is in the direction of the impact force.
- *C*, C_{max}: maximum compression of the dummy rib due to impact.
- VC, VC_{max}, the viscous criterion: the maximum value of the product of the rib velocity and compressive displacement in the dummy occurring during impact.
- F_{avg}: the average force acting on the dummy chest during impact.
- MPa: a unit of stress or pressure, Megapascals or Newtons/mm^2.
- H-point: the center of the dummy hip, reference point for seating position of the dummy.

2.2. NCAP test data

NCAP side impact tests performed by NHTSA on vehicles from 1999 to 2003 were studied. Details of the test procedure and data are available at www.dms.dot.gov, docket 3835, where complete reports of each test are posted. A total of 165 separate tests were analyzed.

Multiple linear regression analysis was performed to relate variables to peak TTI and peak pelvic acceleration using Statview (SAS Institute, Cary, NC, USA). The variables correlated included: (i) vehicle weight as tested, (ii) maximum door crush post impact, (iii) peak door acceleration, (iv) peak door velocity at the midpoint of its vertical height in its rear third section, (v) vertical height, (vi) level of the maximum door crush, (vii) vehicle wheelbase, (viii) dummy H-point to door horizontal dimension, (ix) door panel deflection, and (x) door velocity difference, both described below. The door panel deformation data provided are based on measurements of the deformation of the exterior surface of the door inwards with reference to the initial shape of the door. The door velocity difference is the difference between the peak velocity of the door and the velocity of the vehicle as it is pushed sideways, at the same time point. In addition, vehicles were separated into groups, with and without a thoracic side airbag and peak TTI values were compared using an unpaired *t*-test. Also, peak pelvic accelerations were compared in vehicles with and without a stiff center console. Vehicles