DIFFERENTIAL OCCUPANT KINEMATICS AND FORCES BETWEEN FRONTAL AND REAR AUTOMOBILE IMPACTS AT LOW SPEED: EVIDENCE FOR A DIFFERENTIAL INJURY RISK.

Arthur C. Croft *†‡, Michael T. Haneline †‡, Michael D. Freeman ‡§

* Southern California University of Health Sciences, Whittier, California, USA
† Spine Research Institute of San Diego, San Diego, California, USA
‡ Center for Research into Automotive Safety and Health, Spring Valley, California, USA
§ Oregon Health Sciences University School of Medicine, Portland, Oregon, USA

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NUMEROUS FACTORS ARE BELIEVED to influence the risk for injury to the cervical spine in low speed automobile crashes. These include occupant stature, gender, position, age, pre-exiting health status, and awareness of impending crash. Factors extrinsic to the occupant that are thought to influence the risk for injury include seat back characteristics, head restraint geometry, type of restraint system used, crash speed, relative vehicle mass, and the direction of impact. Several studies have indicated that rear impact crashes are associated with greater risk for injury and, in some cases, a worse prognosis. Epidemiological studies have identified many risk factors, but the retrospective study design and wide ranging variables of real life crash scenarios has not allowed careful comparison of specific variables. We sought to answer the question concerning the possible reasons for the disparity in risk between front vector crashes and rear vector crashes using human subject crash testing.

Materials and Methods

Instrumented human subjects (two males and one female) were placed in instrumented crash test vehicles. Occupant accelerations were recorded for the head, thorax, and lumbar spines. Force and moment analysis were calculated based on head accelerations and the principles of dynamics. Vehicle accelerations, closing velocities, and speed changes were recorded. Volunteers were subjected to three rear impact crashes, two of which were conducted in the unaware mode (subjects had no visual clues as to the time of impact and were distracted with loud music played through ear phones), and one in the aware mode in which the subjects were allowed to brace for the impact. The sequences of crashes—frontal or rear—were staggered among subjects such that two were first struck from the rear and later played the role of the striking driver, while the third subject experienced the reverse sequence, playing first the role of the striking driver and then the role of the struck driver.

In this study, all variables were held constant between frontal and rear impact sequences except the relative positions of the two vehicles. Closing velocities and velocity changes were kept as consistent as possible and varied only minutely. Thus, the only variables with this crossover study design were the impact vectors. In addition to collecting accelerometer data, we recorded the entire crash sequence from the lateral view on high speed 16 mm film and high speed video (both at 500 fps). All footage was carefully analyzed for kinematic time histories and correlated with the accelerometer data. After each crash sequence, subjects were asked for their subjective rating of the crash and, after all sequences were complete, they were asked to compare the frontal crashes with the rear crashes.

Results

For rear impact crash tests, closing velocities ranged from 4.8 km/h to a high of 13.9 km/h, and velocity changes ranged from 2.9 km/h to a high of 10.1 km/h, well within the reported range for possible soft tissue injury. Maximum head linear (x) accelerations in rear crash tests ranged from 2.5 g to 13.3 g (both extremes occurring in the female subject). Maximum head linear (x) accelerations in the frontal crash tests ranged from –1.3 g to –4.5 g. The average head linear (x) accelerations in the

frontal crash tests was –2.5 g, whereas the average head linear (x) acceleration in the rear crash tests was 7.0 g—2.8 times higher than that of the frontal crashes.

Video analysis revealed several noticeable variations between the crashes. In the rear crashes there were two distinct kinematic phases and two distinct bending moments: an initial rearward phase and extension bending moment and a subsequent frontal phase and forward bending moment. Moreover, shear occurred first in the rearward phase and then in the forward phase. Since the female subject (55.5 kg) had appreciably less body mass than the male subjects, she experienced higher accelerations than the males. As a result, her forward shear effect was more pronounced, as was her forward bending moment. However, due to her lesser body mass, she interacted faster with the seat back and head restraint and offered less resistance to their forward motion. This quicker interaction resulted in her earlier and higher amplitude acceleration.

In contrast, the male subjects (82 kg and 86 kg) offered greater resistance to the forward moving seat, effectively delaying their forward acceleration. They also caused the seat back to deflect rearward more than the female subject. This increase in their crash duration during this phase resulted in markedly reduced head linear accelerations. However, due to the fact that the head restraints were positioned low relative to their heads (although they were positioned as high as possible) and also due to the male subjects' greater interaction with the seat backs, the males experienced markedly greater rearward phase extension and bending moments with corresponding less forward phase motion and bending moments. Volunteers rated their subjective experiences in the rear impact crashes as markedly more traumatic or physically unpleasant than in the frontal crashes. For frontal impacts, volunteers had no reservations about undergoing multiple tests, whereas for the rear impacts, they clearly indicated that they would be unwilling to be exposed to additional tests for fear of being injured.

When holding vehicle mass, crash speeds, occupant variables and their interactions constant, the subjects' head accelerations were nearly three times higher in rear impact crash vectors vs. frontals. The resulting occupant kinematics were more complex in the rear impact crash, which also might explain some of the reported differential injury risk. Additionally, it appears that the mechanism of injury in whiplash may vary with occupant mass.

Conclusions

The findings of this study shed some light on possible reasons for the observed difference in injury risk between frontal and rear impact crash injuries reported in clinical and epidemiological literature and will likely have medicolegal implications as well. The results suggest that more attention should be given to crashworthiness in the rear impact crash vector.

As in all human subject crash tests, subjects can be made to be unaware, but not necessarily unprepared. Reactions times are likely to be more brisk for volunteers than for real world occupants. The small study size does not allow a high level of confidence in differential forces and resulting kinematics, but the results were always consistent and the differences were large. Differential risk assignment for real world occupants will require a more comprehensive epidemiological review.

To our knowledge, this is the first study to look specifically at differential effects of rear vs. frontal crashes at low speeds, holding all other variables constant.