Original articles

Human subject rear passenger symptom response to frontal car-to-car low-speed crash tests

Arthur C. Croft DC, MS, MPH, FACO^a, T. Randall Eldridge DC, DACBOH^{b,*}

^a Director of the Spine Research Institute of San Diego (SRISD), San Diego, CA

^b Chiropractor, Private Practice, Denver, CO

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Abstract

Objective: The purpose of this study was to determine whether healthy adult volunteers report symptoms following exposure to low-speed frontal crashes at low velocities.

Methods: Nineteen medically screened, healthy, informed, and willing volunteers (17 men, 2 women; mean age, 37 years) were exposed to low-speed frontal crashes. All volunteers were seated in the rear seat position of the bullet vehicle. Closing velocities ranged from 4.1 to 8.3 mph (mean, 6.7 mph). For the bullet vehicle, the delta V ranged from 1.4 to 3.9 mph with a mean of 2.8 mph.

Results: Eighty-eight percent of volunteers attributed symptoms of discomfort to their crash exposure. All reported symptoms were transient, and none required medical treatment. The mean duration was 1 day.

Conclusions: Even at relatively low speeds, there is no lower threshold below which it can be reasonably assumed that healthy and prepared volunteer rear seat passengers will not sustain some level of minor injury in a frontal collision. Although the reported mean delta V for injured persons in real-world frontal crashes has been reported to be as high as 8.1 mph, this does not offer any insight into the minimum threshold for such injuries among all at-risk vehicle occupants.

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Introduction

The incidence of reported whiplash injury has increased markedly in recent years, and the true incidence may have been underestimated in the past.¹ It is now believed that there are 1.5 million such injuries

in the United States annually and that the total annual economic cost for all motor vehicle crashes in the United States is \$164 billion, whereas the total annual comprehensive cost—an index that considers economic and quality-of-life costs—is \$346 billion.² Neck injuries themselves comprise the single largest group of injuries in motor vehicle crashes,¹ thus imposing a substantial public health burden. A significant number of injuries are reported in crashes at low speeds, and some authors have reported that crash velocity is a poor predictor of injury

* Corresponding author. 7007 E Hampden Ave, Denver, CO 80224. Tel.: +303 758 9000; fax: +303 996 2660.

E-mail address: drrandy724@gmail.com (T. R. Eldridge).

risk in frontal crashes.^{3,4} In many cases of frontal crash injury, no significant vehicle damage is present.⁵ Frontal collisions are the most common crash types; but whiplash neck injuries are more common in rear impact collisions, with rear impact whiplash injuries accounting for 65% of all personal injuries leading to medical disability in Sweden.⁶

Many authors have endeavored to define a minimum crash speed change (or delta V) threshold for neck injury in rear impact collision, relying primarily on the results of human volunteer crash tests as a basis for the hypothesized threshold.⁷⁻¹¹ The concept of an absolute injury threshold for whiplash has been dismissed as methodologically unsound,¹² as the variation in experimental crash tests and among the volunteers for such tests is not representative of the crash circumstances and injury risk seen in the real world. Human volunteer crash tests, although lacking in generalizability for highly individual characteristics such as injury threshold, can generate useful information on occupant kinematics and aid in the design of vehicle interior and seat/head restraint safety innovations. To conduct such tests in a safe and ethical manner and in compliance with applicable institutional review board standards, an adequate understanding of the risks of the testing must be gained. Although all human subject experimentations must be in compliance with the Declaration of Helsinki, special care must be taken with crash testing because even very low speed motor vehicle collisions are a known cause of injury. It is well established through observational study that injury risk varies for both impact vector and occupant position¹³; and thus, a thorough understanding of volunteer injury risk for the various iterations of impact vector and occupant position is critical before embarking on experimental study of human subjects for a given combination. As an example, Brault et al¹⁴ reported 29% minor injury and short-term symptom rate among 42 subjects in the driver's position who were exposed to a rear impact speed change of 2.5 mph, and a 39% injury and short-term symptom rate among 39 of the same subjects subjected to a 5-mph speed change (3 subjects declined further testing after the lower speed test).

To our knowledge, there is no database of clinical responses of subjects exposed to frontal collisions while seated in a rear passenger seat. Thus, the goal of the current study was to subject healthy adult human volunteer passengers to full-scale frontal vehicle-to-vehicle crashes at speeds thought to be below the threshold for minor injury for the majority of healthy and prepared volunteers. The subjects would then be interviewed to determine whether any symptoms

evolved. The hypothesis of the study was that the injury and postcrash symptom risk for such subjects would be close to zero.

Methods

Nineteen volunteers (17 men, 2 women; mean age, 37 years) were exposed to low-speed frontal crashes. Institutional review board approval was obtained from the Spinal Injury Foundation before testing, and informed consent was obtained from all subjects. All volunteers were participants in a larger crash testing program in a capacity other than volunteer and underwent a minimal verbal screening by a physician to determine if there were any overt contraindications to the testing such as recent history of fracture or other trauma or severe arthritic joint changes, ankylosing spondylitis, or other spinal condition that would prohibit normal movement. No expectations from the testing were discussed, and none of the volunteers had any vested interests in the outcome. The volunteers were all seated in the rear seat position with seat belt and shoulder harness fastened. Nine were seated in the inboard (middle seat) position and wore only a lap belt. The vehicle in which the volunteers were seated was a 1992 Ford Crown Victoria (3625 lb), and the vehicle that was struck from the rear was a 1993 Chrysler LeBaron (2740 lb).

Target and bullet vehicle accelerometers consisted of a triaxial block of 3031-050 (gain adjusted to ± 15 g full scale) accelerometers affixed with sheet metal screws to each vehicle's chassis at the approximate static center of gravity. Analog to digital conversion was performed by a 12-bit A/D converter operating with a maximum conversion rate of 330 000 samples per second. All data were collected following the general theory of "SAE (Society of Automotive Engineers) recommended practice: instrumentation for impact test—part 1—electronic instrumentation—J211/1 Mar 95" (SAE, 1996). All accelerometer data were collected at 1000 Hz. Vehicle accelerations were filtered using an SAE class 60 filter. Vehicle changes in velocity were calculated from vehicle acceleration data filtered with an SAE class 180 filter. Occupant accelerometer data were filtered with and SAE class 60 filter. Vehicle speeds were also measured using a fifth wheel (MEA Forensic Engineers & Scientists, Inc, Richmond, British Columbia, Canada) attached to the Crown Victoria. Data were acquired at 128 Hz simultaneously for both vehicles for the period 1 second before to 4 seconds after impacts. Time traps for recording

vehicle impact speed consisted of a custom-built timer interval meter with internal clock calibrated to an National Institute of Standards and Technology-traceable source. The pressure-sensitive tape switches were Tape Switch Type 102A (Tapeswitch Corporation, Farmingdale, NY), requiring 40 oz of pressure for activation.

Subjects were not given any special instructions (eg, to brace or relax) other than to fasten their restraint harnesses. All were observed to be seated in a normal upright posture and facing forward at the time of impact. Several subjects participated in multiple crash tests. Four subjects were exposed to 2 tests, one was exposed to 3 tests, and one was exposed to 4 tests. Closing velocities, which represent the differential velocities of 2 colliding vehicles (sometimes referred to as *impact velocities*), ranged from 4.1 to 8.3 mph. The mean closing velocity in this series was 6.7 mph. For the Crown Victoria, the speed change, which is the change in velocity that results from the collision (also known as the ΔV), ranged from 1.4 to 3.9 mph with a mean of 2.8 mph.

Subjects were interviewed immediately after their participation and again by telephone at approximately 4 weeks posttest. Two male volunteers were unavailable for the 4-week follow-up interview. Volunteers were asked whether they had experienced any symptoms attributable to the crash tests. Symptoms were recorded in terms of their anatomical location, their severity, their frequency, and their total duration. Severity was graded on an ordinal scale of 0 to 4, with 0 indicating no discomfort, 1 indicating “minimal” discomfort, 2 indicating “slight” discomfort, 3 indicating “moderate” discomfort, and 4 indicating “severe” discomfort. Frequency was recorded on the basis of the proportion of a 24-hour period where the symptoms occurred. Duration was recorded in days.

Results

Both test vehicles were inspected carefully after each test, and any damage was noted in detail and photographed before the next test. Both vehicles were equipped with bumper isolators, and piston stroking was recorded after each crash test. Both bumpers were rated as 5-mph bumpers (Expert Autostats version 4.3). Vertical alignment allowed for good contact between bumpers, and no override or underide contacts occurred. Other than minor cosmetic damage, such as scuff marks or superficial gouges in plastic bumper fascias, no structural damage occurred in the any of the tests.

Table 1 Range of symptoms attributed to crash tests

Region/symptom	No. of subjects reporting symptom	Mean duration (d)
Posterior neck discomfort	8	1.5
Shoulder discomfort	4	2.5
Thoracic discomfort	3	1
Headache	2	1
Anterior neck discomfort	2	1
Clavicular discomfort	2	2
Scapular discomfort	2	3
Chest discomfort	2	1
Lumbar discomfort	2	2.5
Temporomandibular joint discomfort	1	1

Two subjects reported no untoward effects from their exposure: one was a 48-year-old man who was exposed to 4 crashes, and the other was a 27-year-old man exposed to a single event. Fifteen (88%) of the participants described some degree of discomfort following the tests. Reported severity ranged from minimal to slight, with a mean severity score of 1.2. There were no reports of discomfort more severe than slight. In all cases, the frequency was described as constant (100% of the time). The duration of symptoms ranged from 15 minutes to 1 week. The mean duration of symptoms was 1 day. The range of symptoms reported by the volunteers is presented in Table 1 and depicted anatomically in Fig 1.

Discussion

The predominant symptoms were posterior neck discomfort, followed in order by shoulder and thoracic spine discomfort. Several of the volunteers had symptoms lasting 2 to 3 days, although these were characterized as minimal or slight in severity only. One subject had slight (2/4) neck discomfort for 1 week. None of the subjects required medical evaluation or care, except for 2 who reported hiring masseurs to relieve their symptoms. In all cases, the subjects were well aware of the impending crash and were belted and positioned in normal postures. None of the crashes resulted in structural damage to either the bullet (Ford) or the target (Chrysler) vehicles.

In rear impact crash tests conducted by other researchers, only transient symptoms have been reported; and as a result, it has been widely

Fig 1. Composite drawing of the areas of discomfort described by the subjects.

hypothesized that the likely threshold speed change associated with cervical spine injury in the real world for this type of crash is about 5 mph.⁷⁻¹¹ These conclusions, however, are not necessarily those of the original researchers conducting the crash tests and do not take into account the practical limitations of human volunteer crash tests, as such testing does not consist of sufficient variation in either crash circumstances or individual occupant injury risk to enable researchers to establish accurate risk thresholds. It has been hypothesized that the number of meaningful permutations of crash circumstance, vehicle factors, and occupant susceptibility variables numbers in the tens of thousands and thus cannot be representatively sampled by the small population of subjects willing to subject themselves to crash testing or the vehicles available for such tests.⁷ Even if one of the purposes of experimental human volunteer crash testing was to establish an injury threshold, there are some proven injury risk variables that cannot be duplicated with such testing for logistic or ethical reasons. Ryan et al,¹⁵ for example, reported an increased injury risk in persons unaware of the impending crash; and Siegmund et al¹⁶ have recently provided an experimentally based explanation for this. Other risk factors reported to increase the risk for occupant injury in low-velocity crashes include a head rotated position,^{4,17} prior neck pain or injury,¹⁷⁻¹⁹ advanced age,²⁰ and degenerative changes in the spine.⁴

Observational studies of real-world crashes and the resultant injuries indicate relatively low mean crash injury thresholds and a lower threshold intercept for speed change near zero for the most susceptible minority of the population. In a study in which real-world crash metrics were recorded using crash pulse recorders, it was reported that the mean crash velocity in rear impact injury cases was 5.1 mph in one group and 6.0 mph in another.²¹ The authors also noted that there was no clear relationship between structural damage and injury risk, a finding concurrent with the fact that there was no structural vehicle damage in any of the crashes in the current study. After multiple crash tests with closing speeds of up to 8.3 mph, neither vehicle in this series sustained any significant structural damage. A common presumption is that injury risk can be reliably gauged by the severity of vehicle damage. However, in lower-speed crashes, individual susceptibility to injury risk is so highly varied that no meaningful conclusions regarding injury can be drawn by merely examining the extent of vehicle damage. The observation that one cannot reliably gauge injury risk on the basis of structural damage alone is consistent with other recent reports.^{4,6,21,22}

One of the surprising findings in the present study was the high rate of minor injury in the volunteers relative to that seen in rear impact studies. It is well established that low-speed rear impact collisions are more likely to produce injury in comparison with

frontal collisions of the same severity. In one recent report, a group of authors examined crash-related injuries reported to a hospital emergency department and then reconstructed the crashes.⁴ They found that the mean delta V of injury for rear impacts was 5 mph, whereas the mean delta V for frontal impact injuries was 8.1 mph. The explanation for this finding has been explored experimentally in a study in which frontal and rear impact crashes were compared using identical crash speeds, vehicles, instruments, and subjects. Head accelerations in the rear impact crashes were a multiple of those in frontal crashes, and the kinematic response was markedly more complicated. Moreover, volunteers rated them markedly less tolerable than the frontal type.²³

Limitations

Although the results of the present study are intended to be generalized in a very narrow manner (ie, safe levels for future testing of frontal collisions with rear seat occupants), there are important limitations to the present study that tended to reduce injury likelihood, relative to the at-risk population. Primarily, this includes the fact that the subjects were mostly male and were relatively young and healthy with an absence of other known risk factors. Positioning and restraint use were also optimized in these tests. Another factor that may have played a role in the high proportion of reported symptoms is the rear seat position of the occupants. For such occupants, there is no opportunity to brace using a steering wheel (for the driver) or the floor pan (for both front occupants); and it is more difficult to gauge the impending collision visually because their outside view is somewhat obscured. The study is also limited in its small sample size, the subjects being aware that they were involved in a study, and the study's lack of a control group and random assignment.

Conclusions

The results of the present study indicate that, although human subject crash testing for rear seat passengers in frontal collisions is unlikely to result in serious or permanent injury, it is possible that some degree of minor and short-lived injury will result in some subjects. This fact must be taken into account when fully informing crash test volunteers of the potential risks of the testing. Although the reported

mean delta V in one study of injured persons in frontal crashes was reported to be as high as 8.1 mph, this finding does not offer any insight into the minimum threshold for such injuries among the universe of exposed vehicle occupants; and the results of the present study suggest that it could be significantly lower depending on the position of the occupant in the vehicle.

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