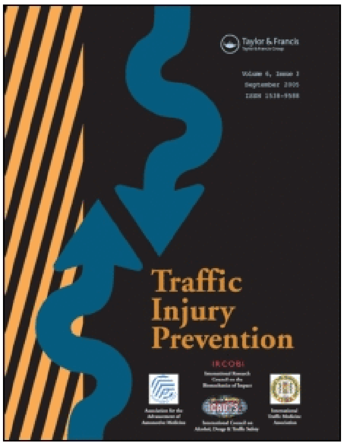


Traffic Injury Prevention
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713456148

Effects of Head Restraint and Seat Redesign on Neck Injury Risk in Rear-End Crashes

Charles M. Farmer [a]; Joann K. Wells [a];Adrian K. Lund [a]
[a] Insurance Institute for Highway Safety, Arlington, Virginia, USA.

To cite this Article Farmer, Charles M. , Wells, Joann K. andLund, Adrian K.(2003) 'Effects of Head Restraint and Seat Redesign on Neck Injury Risk in Rear-End Crashes', Traffic Injury Prevention, 4: 2, 83 — 90
To link to this Article: DOI: 10.1080/15389580309867
URL: http://dx.doi.org/10.1080/15389580309867

Traffic Injury Prevention, 4:83–90, 2003
Copyright © 2003 Taylor & Francis
1538-9588/03 $12.00 + .00
DOI: 10.1080/15389580390205606

Taylor & Francis
Taylor & Francis Group

Effects of Head Restraint and Seat Redesign on Neck Injury Risk in Rear-End Crashes

CHARLES M. FARMER, JOANN K. WELLS, and ADRIAN K. LUND
Insurance Institute for Highway Safety, Arlington, Virginia, USA

Automobile insurance claims were examined to determine the rates of neck injuries in rear-end crashes for vehicles with and without redesigned head restraints, redesigned seats, or both. Results indicate that the improved geometric fit of head restraints observed in many newer vehicle models are reducing the risk of whiplash injury substantially among female drivers (about 37% in the Ford Taurus and Mercury Sable), but have very little effect among male drivers. New seat designs, such as active head restraints that move upward and closer to drivers' heads during a rear impact, give added benefit, producing about a 43% reduction in whiplash injury claims (55% reduction among female drivers). Estimated effects of Volvo's Whiplash Injury Prevention System and Toyota's Whiplash Injury Lessening design were based on smaller samples and were not statistically significant.

Keywords Head Restraints; Insurance Claims; Motor Vehicle Crashes; Whiplash

Rear-end crashes account for approximately 30% of the estimated 6 million police-reported motor vehicle crashes in the United States each year (NHTSA, 2001a). Many of these crashes result in no injury to vehicle occupants, but a significant number lead to symptoms of neck pain for occupants of rear-struck vehicles, often referred to as whiplash-associated disorders. These minor neck injuries have become increasingly common in motorized countries throughout the world (Viano & Olsen, 2001; Zuby et al., 1999).

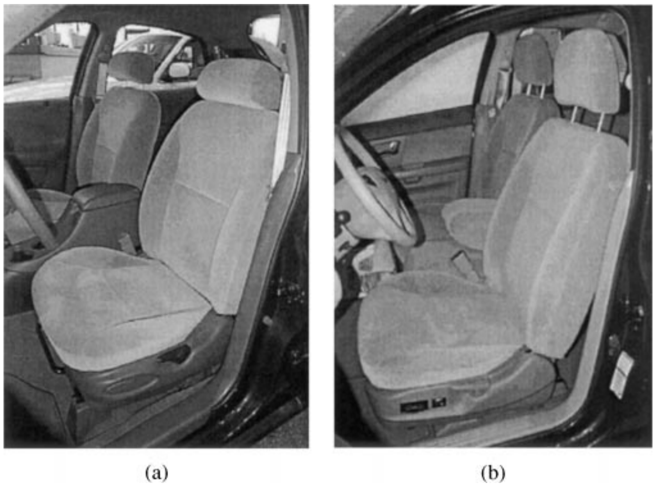
Head restraints, extensions to the tops of vehicle seatbacks meant to support the head in a sudden acceleration, were shown in the 1960s to reduce the neck motion thought to be related to whiplash injuries (Severy et al., 1968). As a result, all passenger cars manufactured for sale in the United States after December 31, 1968, and all pickups, vans, and sport utility vehicles manufactured after August 31, 1991, have been required by law to have head restraints capable of extending at least 700 mm (27.5 in.) above hip level. Head restraints also have been mandated on new passenger cars sold in Canada, Europe, and Australia since the 1970s.

Several studies have evaluated the effectiveness of head restraints in rear-end crashes. Estimated reductions in neck injury risk after the introduction of head restraints ranged from 9% to 18% for passenger cars to 6% for light trucks (Cameron, 1980; Kahane, 1982; O'Neill et al., 1972; States et al., 1972; Walz, 2001). However, neck injury rates still were high (24–37% of drivers in rear-struck cars) even for cars with head restraints. Fixed (integral) head restraints were shown to be more effective than restraints that required manual adjustment to reach the 700 mm height criterion, but this may have been because most drivers failed to properly position the adjustable head restraints (Kahane, 1982). Effectiveness of head restraints improves as they are positioned higher (Chapline et al., 2000; Farmer et al., 1999) and closer to occupants' heads (Olsson et al., 1990).

The Insurance Institute for Highway Safety (IIHS, 2001) has periodically published ratings of head restraint geometry for most passenger vehicles sold in the United States since 1995. Ratings are based on measured distance from the top of the restraint to the top of the head and from the front of the restraint to the back of the head of an average-size male. There are four rating categories: good, acceptable, marginal, and poor. Head restraints measuring higher and closer to the head of an average-size male are rated more favorably. Since these evaluations began there has been a steady improvement in head restraint geometry. For the 1995 model year, only 13 of the 164 cars evaluated (8%) received good or acceptable head restraint ratings. For the 2001 model year, however, 83 of the 166 cars evaluated (50%) received good or acceptable ratings.

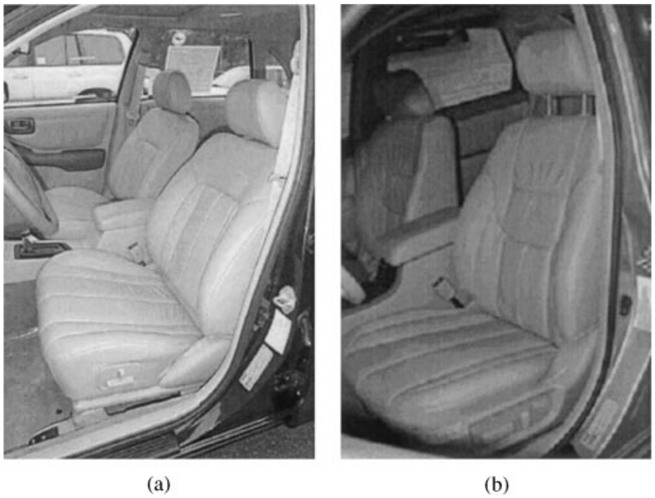
Received 28 October 2002; accepted 15 December 2002.

Address correspondence to Charles M. Farmer, Insurance Institute for Highway Safety, 1005 North Glebe Road, Arlington, VA 22201, USA. E-mail: research@iihs.org



(a) (b)

Figure 1 (a) 1999 Ford Taurus vs. (b) 2000 Ford Taurus with improved head restraint geometry.



(a) (b)

Figure 2 (a) 1999 Toyota Avalon vs. (b) 2000 Toyota Avalon with Whiplash Injury Lessening (WIL) system.

In response to criticism that the U.S. standard allows for head restraints that are too low, the National Highway Traffic Safety Administration (NHTSA, 2001b) proposed a number of changes to the requirements in 2001. Key among these is a change in the height requirement to that currently mandated by the European Union. The proposed standard would require head restraints in all new passenger vehicles to reach minimum heights of 750 mm above the hip when adjusted to the lowest position and 800 mm when adjusted to the highest position. In addition, the horizontal distance from the restraint to the head of a prototypical seated occupant must be no more than 50 mm.

As evidenced by the improvements in IIHS ratings, manufacturers have begun redesigning head restraints and seating systems in advance of government regulation. Some seating systems have undergone dramatic changes. The Ford Taurus and its corporate twin, the Mercury Sable, had head restraints rated poor for the 1999 model year. For the 2000 model year, head restraints in the Taurus/Sable measured 90 mm higher and 20 mm closer to the head of an average-size male, thus bringing them into the acceptable category (Figure 1).

Some manufacturers have begun to introduce designs that go beyond simple geometric improvements. Toyota has devised a seat that it calls the Whiplash Injury Lessening (WIL) seating system (Sekizuka, 1998). It is designed to allow an occupant's upper back to sink farther into the seatback, thus reducing the differential movement of the head and torso in a sudden acceleration. It also has a slightly higher seatback and head restraint than earlier seating systems (Figure 2). The WIL system was introduced in some versions of the 1999 Lexus RX300 and then made standard for the 2000 Toyota Avalon, Celica, and Echo.

Volvo, whose head restraints were receiving good ratings for geometry even in 1995, introduced the Whiplash Injury Prevention System (WHIPS) for the 1999 Volvo S80 and 2000 Volvo S70 (Lundell et al., 1998). The head restraint is unchanged, but a hinge at the base of the seatback yields and partially rotates under sufficient loading, thus reducing the forward acceleration of the occupant's torso (Figure 3).

The Saab Active Head Restraint (SAHR) is a mechanical system that moves the head restraint upward and forward in response to sudden pressure from an occupant against the seatback (Wiklund & Larsson, 1998) (Figure 4). It was first introduced in Europe in the 1998 Saab 9-5, and in the United States in the 1999 Saab 9-3 and 9-5. SAHR is meant to overcome the problem of poorly adjusted head restraints by automatically moving into an optimal position when needed. Laboratory testing has shown that SAHR, even when adjusted to its lowest position, controls the head and neck movement of an average-size male as well as a fixed head restraint with good geometry (Linder et al., 2001; O'Neill, 2000; Zuby et al., 1999). General Motors has incorporated an active head restraint similar to SAHR in its

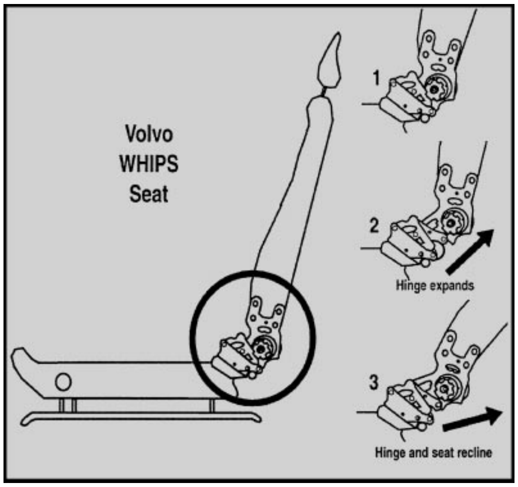


Figure 3 Volvo Whiplash Injury Prevention System (WHIPS) design.

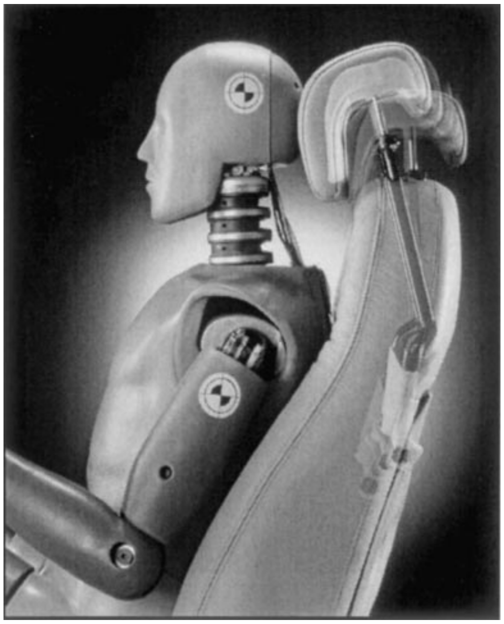


Figure 4 Saab Active Head Restraint (SAHR).

“catcher’s mitt” seating system, beginning with the 2000 Buick LeSabre, Pontiac Bonneville, and Oldsmobile Aurora. Nissan also has adopted a similar active head restraint, beginning with the 2000 Infiniti Q45.

Viano and Olsen (2001) compared insurance records in Sweden over an 18-month period for Saab 900 and 9000 cars with standard head restraints and Saab 9-3 and 9-5 cars with active head restraints. Occupants of rear-struck cars were mailed questionnaires asking them if they experienced neck pain after the crash and, if so, how many weeks the pain lasted. The sample included 85 front-seat occupants of cars with standard head restraints and 92 front-seat occupants of cars with SAHR. Among occupants of cars with SAHR, 41% reported some level of neck pain after the crash compared with 53% of those in cars with standard head restraints. When short-term pain was discounted, the differences were even larger. Only 4 (4%) of those in cars with SAHR reported neck pain lasting at least 1 week compared with 18% of those in cars with standard head restraints.

The three new approaches to reducing whiplash injury risk—WIL, WHIPS, and active head restraints—have been justified both theoretically and in the laboratory. However, with the exception of the Viano and Olsen (2001) study, they remain unproven in real-world crashes. Improved head restraint geometry has been linked to lower neck injury rates (Chapline et al., 2000; Farmer et al., 1999), but the comparisons were made among different vehicle models. A better comparison would be between vehicles of the same model, yet with differing head restraints. The purpose of the present study was to examine real-world neck injury rates for vehicles with each of the four systems—active head restraints, improved head restraint geometry, WIL, and WHIPS—and compare them with the same vehicle models with standard head restraint and seating systems. Using data from U.S. automobile insurance claims, information was obtained on more than 2,500 rear-struck vehicles.

METHOD

Study vehicles and the model years for which they had redesigned head restraints, seats, or both are listed in Table I. In all cases, earlier models were required to be comparable in rear structure to the models with redesigned seats. Thus, any change in rear-impact injury risk could not be attributed to differences in the structural designs of the vehicles. Due to this restriction some vehicles with redesigns extending beyond the seating systems, such as the Oldsmobile Aurora and Toyota Celica, could not be included.

This restriction to changes only in the seating system should also serve to minimize differences in the driver populations of the early and later models. Consumers pay little attention to head restraint design, and changes in the structure of the seatback may be imperceptible. So the drivers of the later models in Table I likely were very similar to the drivers of the early models. Even

Table I Case vehicles

	Before design change		After design change		
Vehicle class	Model	Model years	Model	Model years	Design change
Active head restraint	Buick LeSabre	1999	Buick LeSabre	2000–2001	AHR
	Pontiac Bonneville	1999	Pontiac Bonneville	2000–2001	AHR
	Saab 900	1996–1998	Saab 9-3	1999–2001	AHR
	Saab 9000	1996–1998	Saab 9-5	1999–2001	AHR
	Infiniti Q45	1998–1999	Infiniti Q45	2000[a]–2001	AHR
	Infiniti QX4 4 × 4	1999–2000	Infiniti QX4 4 × 4	2001	AHR
Improved geometry	Ford Taurus	1999	Ford Taurus	2000–2001	IIHS
	Mercury Sable	1999	Mercury Sable	2000–2001	IIHS
Advanced seating system	Toyota Avalon	1999	Toyota Avalon	2000–2001	WIL
	Lexus LS 400	1999–2000	Lexus LS 430	2001	WIL
	Volvo S70	1999	Volvo S70	2000	WHIPS

Abbreviations: AHR, active head restraint; IIHS, significant change in head restraint geometry according to Insurance Institute for Highway Safety measurements; WIL, Whiplash Injury Lessening system; WHIPS, Whiplash Injury Prevention System.

[a] Only models built after November 1, 1999.

so, there may have been differences in the exposure of early and later models. Walz (2001) reported that crashes involving older vehicles are less likely to be reported than crashes involving newer vehicles unless an injury is involved. This would tend to inflate injury rates for older vehicles. The vehicles in Table I, however, were all relatively new during the period of study.

Eligible crashes were those in which the study vehicles were struck in the rear by the fronts of other passenger vehicles. Because many low-severity crashes and associated neck injuries are not reported to police, automobile insurance claims are the best source of information. The driver of the striking vehicle typically is deemed at fault, so many of these crashes lead to property damage liability claims against the insurer of the striking vehicle.

Three large insurance companies agreed to provide access to their automobile claim files: Nationwide Insurance, the Progressive Corporation, and State Farm Insurance. State Farm, Progressive, and Nationwide rank first, fourth, and fifth, respectively, in market share of U.S. automobile insurance. Together they account for 29% of all personal automobile insurance premiums paid in the United States. Data were not collected from states with no-fault insurance systems. No-fault systems vary considerably from state to state, and these differences can influence the rates of claims under these coverages.

An electronic database maintained at State Farm headquarters allowed for identification of automobile insurance claims by type of coverage, date, vehicle make and model, and location of damage on the vehicle. This database was searched for all property damage liability claims involving rear damage to the vehicles listed in Table I and occurring between January 1, 1999, and June 30, 2001. A total of 2,732 State Farm claims were identified.

Identification of eligible claims was not feasible using the electronic databases maintained by Nationwide and Progressive. As an alternative, the Highway Loss Data Institute provided property damage liability estimate files processed by CCC Information Services, Inc. for collisions occurring between January 1, 2000, and April 30, 2001. CCC is one of the major suppliers of software and communication tools to automobile insurance and collision repair facilities throughout the United States (and the only one currently supplying collision estimate data to the Highway Loss Data Institute). These files included the name of the insurance company, insurance company claim number, location of damage on each vehicle, and vehicle identification numbers from which the vehicle make, model, and model year could be determined. Rear damage claims from Nationwide and Progressive for vehicles in Table I were extracted from the files. A total of 684 Nationwide claims and 668 Progressive claims were identified. Because CCC is not the only collision estimate service used by Progressive and Nationwide, this set did not include all rear damage property damage liability claims for the period of interest. It can, however, be considered a reasonable sample.

State Farm regional offices were requested to send paper claim files to the corporate office in Bloomington, Illinois, for examination during December 2001, unless the claim file information was available electronically. A team of researchers read through each claim, extracting information on crash circumstances, vehicle damage, driver demographics, and injury diagnosis and treatment. Claim records were not obtained from Georgia, North Carolina, South Carolina, and Virginia. Also, approximately 30% of the eligible claims, after detailed examination, were found to be outside the parameters of the study. Typically, these rejected claims were for crashes that involved more than two vehicles or for rear-struck vehicles that were parked and unoccupied (and thus irrelevant to a study of neck injury). Of the 2,732 State Farm claim files initially identified, 1,790 were deemed suitable for the study.

Eligible Progressive claims were examined at the regional level. In April 2002, claims representatives and managers at regional Progressive offices read through the selected claims for their region and extracted the same types of information as collected at State Farm. Again, some claims were rejected as being outside the parameters of the study. Of the 668 Progressive claim files initially identified, 418 were deemed suitable for the study.

Nationwide claim files were examined in Columbus, Ohio, in July 2002. Most claims information is stored electronically by Nationwide, so researchers searched the database for the required variables. In addition, regional offices were asked to ship paper claim files to Columbus for examination. Of the 684 Nationwide claim files initially identified, 433 were deemed suitable for the study.

The study vehicles were divided into four head restraint classes according to the type of design change: active head restraint (Buick LeSabre, Pontiac Bonneville, Saab 9-3 and 9-5, Infiniti Q45, Infiniti QX4), improved head restraint geometry (Ford Taurus, Mercury Sable), WIL (Toyota Avalon, Lexus LS 430), and WHIPS (Volvo S70). However, because vehicles within a head restraint class may have widely varying neck injury rates, overall rates for a class were adjusted to standardize the representation of each vehicle model. Calculations and statistical significance tests were mathematically equivalent to those of the standardized mortality ratio as discussed by Breslow and Day (1987). For each vehicle class a weighted average of the neck injury rates for each model before the design change was computed, using the number of crash involvements after the design change as weights. This weighted average represented the expected neck injury rate for the class if the individual vehicle rates had remained unchanged and only the representation of each vehicle model had changed. As an adjustment back to the initial vehicle distribution, the observed neck injury rate after the design change then was multiplied by the ratio of the neck injury rate before the design change to the expected neck injury rate.

Neck injury rates of struck vehicle drivers before and after each design change were computed for each insurer separately and for all three insurers combined. A simplistic estimate of the effectiveness of each design change was computed as the relative difference between the adjusted neck injury rate after the design change and the neck injury rate before the design change.

The terms used here are before and after, but the reader should keep in mind that this refers to vehicles of different model years observed during the same time period. Thus, the comparisons are not likely to be affected by possible temporal trends in neck injury rates or neck injury claiming behavior.

The effectiveness of each design change also was estimated after accounting for observed differences in other crash characteristics. For each of the four seating design classes, logistic regression analysis was used to model the likelihood of driver neck injury as a joint function of insurer, vehicle model, driver gender, direction of impact, repair cost, damage severity, and whether or not the new design was present. Direction of impact to the struck vehicle was defined as either rear corner (5 o'clock or 7 o'clock) or rear center (6 o'clock). Repair cost was defined as either less than $1,000 or at least $1,000. Damage to the struck vehicle was defined as severe if the frame or trunk floorpan required repair or if the vehicle was declared a total loss and minor or moderate otherwise. Previous work on similar data (Farmer et al., 1999) has demonstrated that neck injury rates are higher for rear center impacts than for corner impacts and for impacts causing more damage, whether measured by repair cost or vehicle parts repaired.

Table II Changes in driver neck injury rates—State Farm, Nationwide, and Progressive combined

		Number of drivers		Percent with neck injury		
Vehicle class	Model	Before	After	Before	After^a	Percent change
Active head restraint	Buick LeSabre	87	180	21.8	10.9	−50*
	Pontiac Bonneville	67	50	26.9	14.3	−47
	Saab 900/9-3	112	84	16.1	9.0	−44*
	Saab 9000/9-5	15	68	20.0	13.5	−33
	Infiniti Q45	45	7	17.8	33.8	+90
	Infiniti QX4	104	20	14.4	10.3	−29
	Total	430	409	18.8	10.5	−44*
Improved geometry	Ford Taurus	638	328	24.3	22.0	−10
	Mercury Sable	129	95	24.8	18.7	−25
	Total	767	423	24.4	21.2	−13
WIL	Toyota Avalon	191	242	17.3	18.0	+4
	Lexus LS 400/430	63	4	12.7	0.0	−100
	Total	254	246	16.1	16.6	+3
WHIPS	Volvo S70	65	47	24.6	17.0	−31

Abbreviations: WIL, Whiplash Injury Lessening system; WHIPS, Whiplash Injury Prevention System.

[a] Adjusted so that the representation of each vehicle model and each insurer is consistent with the before group.

*$p < .05$.

RESULTS

Driver neck injury rates varied somewhat across the three insurers. Some of this may have been due to the inherent imprecision of estimates based on small samples, but even those based on larger samples exhibited significant variability. Neck injury rates for drivers of the 1999 Ford Taurus (the model year before the design change) were 26% (102/391) for State Farm claims, 29% (37/126) for Progressive, and 13% (16/121) for Nationwide. Neck injury rates for model years after the design changes also varied across insurers, so estimates of the effectiveness of these changes were sometimes inconsistent. One notable exception was the class of vehicles with active head restraints. For all three insurers, active head restraints were associated with large reductions in neck injury rates. Also, the injury rates for the three insurers were similar.

Driver neck injury rates for the three insurers combined (2,641 suitable claims from 37 states and the District of Columbia) are summarized in Table II. Injury rates before the seating system design changes ranged from 13% for the Lexus LS 400 to 27% for the Pontiac Bonneville. By comparison, injury rates after the design changes were lower for 9 of the 11 vehicle models. However, some rates were based on very small samples and likely were unreliable. For example, injury rates were based on only 15 drivers (3 of whom had neck injuries) for the Saab 9000 and on only 4 drivers for the Lexus LS 430.

The combined neck injury rate for each vehicle class after the design change was adjusted so that the representation of each vehicle model and each insurer was consistent with that before the design change. For example, in the model year before the design change, the overall neck injury rate for Ford Taurus drivers was 24.3% (155/638). In the model years after the design change, the data included 328 Ford Taurus drivers (216 from State Farm, 59 from Progressive, 53 from Nationwide), and 73 of these had neck injuries (56 from State Farm, 8 from Progressive, 9 from Nationwide). A straight combination of these would have produced an overall "after" neck injury rate of 22.3% (73/328) for the Ford Taurus. However, a weighted average of the "before" neck injury rates for each insurer using the "after" sample sizes yielded an expected neck injury rate of 24.6%, or 1.0% higher than the overall "before" neck injury rate. The overall neck injury rate for the Ford Taurus with improved geometry was divided by 1.01 to adjust for this expected increase. Thus, the adjusted neck injury rate for the Ford Taurus with improved geometry was 22.0%. Combinations of neck injury rates across vehicle models proceeded in the same manner.

According to Table II, active head restraints were associated with a statistically significant 44% reduction in neck injury rates. Ford's improved head restraint geometry was associated with a 13% reduction in neck injury rates, although not statistically significant ($p = 0.17$). Volvo's WHIPS was associated with a 31% reduction in neck injury rates, but this was not statistically significant due to small sample sizes. Estimated neck injury rates before and after Toyota's WIL seat were approximately the same.

Some of the effects presented in Table II may have been confounded by differences in the "before" and "after" distributions of crash severity. For example, severe impacts accounted for 10% of the sampled claims in the improved geometry class before the design change and 12% after the design change. Prior research has reported higher neck injury claim rates as impact severity increases (Farmer et al., 1999), so the increase in severe impacts sampled may have led to underestimates of effectiveness for Ford's improved head restraint geometry. On the other

Table III Logistic regression on the odds of driver neck injury for active head restraints—odds ratios

Effect	Male drivers	Female drivers	Total
Direction of impact			
Rear corner vs. center	0.62	0.46*	0.56*
Repair cost			
Less than \$1,000 vs. at least \$1,000	0.43*	0.35*	0.38*
Damage severity			
Minor or moderate vs. severe	0.76	0.40*	0.57*
Seating system design			
New vs. old	0.69	0.45*	0.57*

*$p < .05$.

hand, a decrease in the number of women from 54% of the sampled drivers before the design change to 49% after the design change may have led to overestimates of effectiveness for Ford's improved head restraint geometry.

Logistic regression was used to account for the effects of crash severity using three covariates: direction of impact, repair cost, and damage severity. Interactions of these covariates with an indicator of old or new seating system design were originally included in the regression, but they were not statistically significant and therefore were excluded from further analyses. Variables representing the insurers (Nationwide, Progressive, State Farm) and the vehicle models in each class were included in the regression. For each vehicle class three logistic regression analyses were conducted, one for each driver gender and one combined (with gender as a variable in the regression model). Results for the active head restraint class are summarized in Table III. The likelihood of neck injury was significantly lower in rear corner compared with rear center impacts. Neck injury risk also was lower for vehicles less severely damaged. Most importantly, neck injury risk was significantly lower for vehicles with active head restraints.

Effectiveness estimates for each of the four design changes are summarized in Table IV. After accounting for the influences of driver gender and crash severity, active head restraints were associated with a statistically significant 43% reduction in overall driver neck injury rates, a statistically significant 55% reduction among female drivers and a nonsignificant 31% reduction among male drivers. The improved head restraint geometry in the Ford Taurus and Mercury Sable was associated with a nonsignificant 18% reduction in overall driver neck injury rates but a statistically significant 37% reduction among female drivers. Effects of Volvo's WHIPS and Toyota's WIL seat design changes were not statistically significant, even among female drivers.

Table IV Estimates of percent effect on driver neck injury risk (and 95% confidence limits) based on logistic regression

Design change	Male drivers	Female drivers	Total
Active head restraint	−31 (−65, +36)	−55* (−76, −17)	−43* (−63, −11)
Improved geometry	+8 (−31, +68)	−37* (−58, −3)	−18 (−39, +11)
WIL	+13 (−48, +144)	+23 (−42, +159)	+15 (−32, +95)
WHIPS	−1 (−82, +438)	−69 (−94, +59)	−49 (−83, +53)

Abbreviations: WIL, Whiplash Injury Lessening system; WHIPS, Whiplash Injury Prevention System.

*$p < .05$.

DISCUSSION

Worldwide interest in the problem of whiplash injury in motor vehicle crashes is bringing rapid changes in seat and head restraint designs intended to reduce the forces on the neck during rear-end crashes. By far the most common change is improvement in the geometry of head restraints so that they are likely to be high enough and close enough to the backs of the heads of more occupants (IIHS, 2001). This may also involve other seating system changes. In the present study, the effects of head restraint changes cannot be separated from the effects of other possible changes to the seat. Prior research has indicated that vehicles with good head restraint geometry have substantially lower risk of whiplash injury claims following rear-end crashes than do vehicles of comparable size with poor geometry (Farmer et al., 1999). Results for the improved head restraint geometry in the Ford Taurus and Mercury Sable in the present study indicated similarly large reductions in whiplash injury risk (18%), but the benefits appeared to occur primarily among female drivers (37% reduction). This gender difference in effectiveness of improved head restraint geometry is surprising, given that the definition of good geometry is based on the ability of restraints to fit taller male occupants. However, a similar gender difference was observed by Farmer et al. (1999). In any case neck injury rates tend to be higher for women than men, so these large reductions in risk are occurring for the population most at risk of neck injury in rear impacts (Chapline et al., 2000).

Drivers may object to head restraints that they consider to be too close to their heads or blocking their rear view. In response to such complaints, Ford again changed the geometry of head restraints in the 2002 Taurus. Head restraints in the 2002 model were narrower and lower than those of the 2001 model and received an IIHS rating of marginal. The effect of these geometric deteriorations on neck injury risk should be the subject of future research.

Results of this study also are encouraging for two new seat designs that alter the dynamic performance of the seat or head restraint in a crash: active head restraints, which move upward and forward as an occupant is loaded by the seatback, and Volvo's WHIPS seat, which deforms as it loads an occupant. Active head restraints reduced whiplash injury claims by an estimated 43%. The estimated effect of WHIPS was even larger (49%) but was not statistically significant because of small sample size ($p = 0.23$). The effect for WHIPS will need to be monitored to be sure this effect continues. As with improved head restraint geometry in the Taurus and Sable, active head restraints and WHIPS appear to have been more beneficial for women than for men, although the gender difference for active head restraints is not so large.

Results for the third seat redesign, the Toyota WIL seat, were less encouraging. Neck injury rates were essentially similar for the new seats as for the older seat designs. It may be noteworthy that neck injury rates for the Toyota vehicles studied were somewhat lower than the other vehicle groups in the "before" period (16% vs. 19–25% in the other head restraint groups) (Table II). Even so, there still was room for improvement, as indicated by the very low rates (10%) for the vehicles with active head restraints. Results for the WIL seat are particularly puzzling because the seat redesign should accomplish some of the same objectives as Volvo's WHIPS. That is, the WIL seat is intended to reduce the difference in acceleration of the head and torso early in the rear crash sequence. However, the WIL seat does not include the plastic deformation built into the WHIPS seatback response, and the different results could reflect a more elastic response of the WIL seat.

Krafft et al. (2002) reported a positive correlation between crash severity and the duration of neck injury symptoms. Although duration of symptoms could not be consistently determined in the present analysis, it may be that certain of these redesigned seating systems are more effective at preventing longer-term injuries than short-term injuries. If so, then the effectiveness estimates based on severe crashes should be higher than those based on minor or moderate severity crashes. Conversely, if the systems are effective only for short-term injuries, the effectiveness estimates based on severe crashes should be lower. Interaction terms in the logistic regressions representing these differences were not statistically significant. Thus, the data available do not provide evidence of differing effectiveness by crash severity.

It would have been useful in this study to include a control group of vehicles, similar to the study vehicles but with no changes in seating system design. A constant neck injury rate across the model years of the control group would have added weight to the conclusion that the observed reduction in injury risk among study vehicles was due to the redesigned seating systems. Defining such a group, however, proved impracticable. So, it is possible that some of the reduction in neck injury risk was due to differences in exposure of the vehicle models with and without redesigned seating systems.

It was necessary to gather data from three disparate sources. Although the logistic regression models did not detect any significant differences in neck injury rates across the insurers (after accounting for the covariates), the analyses may have been somewhat affected by differences in the data storage systems used by the three companies. Also, researchers extracting the information, although trained as consistently as possible in the interpretation and coding of study variables, differed in their levels of familiarity with insurance claims data. The distribution of claims across states also differed for the three companies, and the claiming behavior of motorists may differ across states. This may explain some of the differences in results across insurers.

In conclusion, it appears that the improvements seen in head restraint geometry during the past several years are reducing the incidence of whiplash injury at least among women, the population most likely to experience whiplash. Further risk reductions appear likely as more vehicles adopt active head restraints or the Volvo WHIPS concept, although the benefit may continue to be greater for women than for men. It is unclear why the Toyota WIL seat does not show similar reductions in whiplash injury risk, and more research is needed to understand the differences in biomechanical responses associated with these seat designs. It also will be important to continue to monitor the performances of these seats, as the small sample sizes mean that some of the observed effects, particularly that of the Volvo WHIPS, in this study are uncertain.

ACKNOWLEDGMENT

The authors acknowledge the efforts of all those who participated in the gathering of data. In particular, they thank William Ayscue of Nationwide, Leslie Kolleda and Nathan Hoellein of Progressive, and Steve Roberson and Melissa Miles of State Farm. This work was supported by the Insurance Institute for Highway Safety.

REFERENCES

Breslow, N., Day, N. (1987) *Statistical Methods in Cancer Research: The Design and Analysis of Cohort Studies*, Vol. 2, International Agency for Research on Cancer, Lyon, France.

Cameron, M. H. (1980) *The Effect of Australian Design Rule 22A for Head Restraints*, Report No. CR-12, Department of Transport, Office of Road Safety, Melbourne, Australia.

Chapline, J. F., Ferguson, S. A., Lillis, R. P., Lund, A. K., Williams, A. F. (2000) Neck Pain and Head Restraint Position Relative to the Driver's Head in Rear-End Collisions, *Accid. Anal. Prev.*, Vol. 32, pp. 287–297.

Farmer, C. M., Wells, J. K., Werner, J. V. (1999) Relationship of Head Restraint Positioning to Driver Neck Injury in Rear-End Crashes, *Accid. Anal. Prev.*, Vol. 31, pp. 719–728.

Insurance Institute for Highway Safety (IIHS). (2001) *Status Report*, Vol. 36, No. 9, Arlington, VA.

Kahane, C. J. (1982) *An Evaluation of Head Restraints: Federal Motor Vehicle Safety Standard 202*, Report No. DOT-HS-806-108, National Highway Traffic Safety Administration, Washington, DC.

Krafft, M., Kullgren, A., Ydenius, A., Tingvall, C. (2002) Influence of Crash Pulse Characteristics on Whiplash Associated Disorders in Rear Impacts—Crash Recording in Real Life Crashes, *Traffic Inj. Prev.*, Vol. 3, pp. 141–149.

Linder, A., Olsson, T., Truedsson, N., Morris, A., Fildes, B., Sparke, L. (2001) Dynamic Performances of Different Seat Designs for Low to Medium Velocity Rear Impact, *Proc. 45th Annual AAAM*, pp. 187–201.

Lundell, B., Jakobsson, L., Alfredsson, B., Jernström, C., Isaksson-Hellman, I. (1998) Guidelines for and the Design of a Car Seat Concept for Improved Protection Against Neck Injuries in Rear End Car Impacts, SAE Technical Paper Series 980301, Society of Automotive Engineers, Warrendale, PA.

National Highway Traffic Safety Administration (NHTSA). (2001a) *Traffic Safety Facts, 2000*, Report No. DOT HS-809-337, U.S. Department of Transportation, Washington, DC.

National Highway Traffic Safety Administration (NHTSA). (2001b) Notice of Proposed Rulemaking: Federal Motor Vehicle Safety Standards; Head Restraints, *Federal Register*, Vol. 66, No. 3, pp. 968-999.

Olsson, I., Bunketorp, O., Carlsson, G., Gustafsson, C., Planath, I., Norin, H., Ysander, L. (1990) An In-Depth Study of Neck Injuries in Rear-End Collisions, *Proc. IRCOBI Conf.*, pp. 269–280.

O'Neill, B. (2000) Head Restraints—The Neglected Countermeasure, *Accid. Anal. Prev.*, Vol. 32, pp. 143–150.

O’Neill, B., Haddon, W., Jr., Kelley, A. B., Sorenson, W. W. (1972) Automobile Head Restraints—Frequency of Neck Injury Claims in Relation to the Presence of Head Restraints, *Am. J. Public Health*, Vol. 62, pp. 399–406.

Sekizuka, M. (1998) Seat Designs for Whiplash Injury Lessening, *Proc. 16th ESV Conf.*, pp. 1570–1578.

Severy, D. M., Brink, H. M., Baird, J. D. (1968) Backrest and Head Restraint Design for Rear-End Collision Protection, SAE Technical Paper Series 680079, Society of Automotive Engineers, Warrendale, PA.

States, J. D., Balcerak, J. C., Williams, J. S., Morris, A. T., Babcock, W., Polvino, R., Riger, R., Dawley, R. E. (1972) Injury Frequency and Head Restraint Effectiveness in Rear-End Impact Accidents, *Proc. 16th Stapp Car Crash Conf.*, pp. 228–245.

Viano, D. C., Olsen, S. (2001) The Effectiveness of Active Head Restraint in Preventing Whiplash, *J. Trauma*, Vol. 51, pp. 959–969.

Walz, M. C. (2001) The Effectiveness of Head Restraints in Light Trucks, Report No. DOT HS-809-247, National Highway Traffic Safety Administration, Washington, DC.

Wiklund, K., Larsson, H. (1998) Saab Active Head Restraint (SAHR)—Seat Design to Reduce the Risk of Neck Injuries in Rear Impacts, SAE Technical Paper Series 980297, Society of Automotive Engineers, Warrendale, PA.

Zuby, D. S., Vann, D. T., Lund, A. K., Morris, C. R. (1999) Crash Test Evaluation of Whiplash Injury Risk, *Proc. of the 43rd Stapp Car Crash Conf.*, pp. 267–278.