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Neck pain and head restraint position relative to the driver's head in rear-end collisions

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Abstract

This two-year investigation was designed to estimate the incidence of driver neck pain in rear-struck vehicles involved in two-vehicle collisions and to determine the relationship between neck pain and specific vehicle, human, and environmental factors. Neck pain percentages were significantly higher for female (45%) than for male (28%) drivers. For female and male drivers, neck pain likelihood increased as head restraint height decreased below the head's center of gravity, although this effect was significant only for females. Head restraint backset, the horizontal distance measured from the back of the driver's head to the front of the head restraint, was not found to be related to neck pain for female drivers. Backset trends for male drivers could not be evaluated because few male drivers had head restraints that were high enough for backset to be relevant. Reported neck pain decreased for older drivers (females only), drivers in less severe crashes, and drivers in heavier cars (females only); all head restraint analyses were adjusted for these characteristics. Women, and most likely men, in the United States would benefit greatly from international harmonization to European head restraint standards. Until then, both women and men should be encouraged to adjust their adjustable head restraints, if possible, behind their heads' centers of gravity and to sit with the backs of their heads as close as possible to their head restraints. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Head restraints; Neck pain; Neck injury; Whiplash; Rear-end collisions; Rear-end crashes

1. Introduction

Although infrequently resulting in fatal injuries, rear-end collisions are very common and a frequent cause of minor injuries. The Insurance Research Council (1994) estimated that 66% of insurance claims for bodily injuries in 1992 included neck sprains. For 40% of these claims it was the most serious injury, and these claims accounted for 27% of all costs for bodily injury claims.

The term 'whiplash' is used to describe a range of injuries and associated disorders of the neck from mild muscle strain to tearing of various soft tissues in the neck, nerve damage, and even disc damage. Symptoms associated with these injuries can include neck pain and soreness, headaches, decreased range of motion, and tingling in the arms. Typically these symptoms do not last long, but in some cases they can continue for several months. The biological causes of whiplash injury have long been debated due to lack of objective signs and symptoms for use in diagnosis; however, there is agreement that the injuries result from sudden differential movement of head and torso.

Although precise mechanisms that produce whiplash injuries in rear-end crashes are not fully understood, a countermeasure, head restraints, has been known for decades. Head restraints were first installed in automobiles in the mid-1950s (Ruedemann, 1957). Currently, Federal Motor Vehicle Safety Standard (FMVSS) 202 requires all passenger vehicle head restraints to extend at least 27.5 inches above the seating reference point in the highest position. Head restraints were mandated for passenger cars manufactured for sale in the United

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States beginning January 1, 1969; a similar mandate for trucks, multipurpose passenger vehicles (such as passenger vans and utility vehicles), and buses with gross vehicle weight ratings of 10 000 lbs or less took effect September 1, 1991.

Studies conducted subsequent to implementation of the U.S. head restraint requirement consistently have shown lower levels of neck injury incidence for drivers rear-ended in head restraint-equipped cars. Based on a review of 5663 rear-end collision insurance claims in Los Angeles, CA, O'Neill et al. (1972) determined a neck injury incidence of 29% for drivers in cars not equipped with head restraints and 24% for head restraint-equipped cars, an 18% reduction. States et al. (1973) estimated a 14% reduction in whiplash injury frequency for head restraint-equipped cars, based on information obtained for cars struck in the rear during a 3-month period in Rochester, NY, including whether head restraints were fixed or adjustable and, if adjustable, whether they were in the down, midway, or up position. Occupants of these rear-struck cars were contacted by mail or phone concerning the extent and nature of their injuries. Analysis of three years of Texas crash data (Kahane, 1982) showed head restraints were 13% effective in reducing *overall* injuries.

Though all new model vehicles have head restraints in compliance with FMVSS 202, most restraints are not high enough to protect an average-size male. This is primarily due to the fact that most head restraints in the United States are adjustable and are often left in the lowest (down) position. In the fall of 1995, the National Highway Traffic Safety Administration (NHTSA, 1996) conducted a survey of the relative positions of occupant heads and head restraints in 282 vehicles. Of these vehicles, 23% had fixed head restraints, with 77% of these restraints positioned at or above the occupants' ears. A lower percentage (59%) of the 77% of adjustable head restraints was positioned at or above the occupants' ears. About half the adjustable head restraints were left in the lowest position. According to NHTSA, three-quarters of those left in the lowest position could have been raised to correctly position the restraints with respect to the occupants' heads. O'Neill et al. (1972) observed drivers in 4983 moving domestic passenger cars with head restraints in the Los Angeles, CA, and Washington, D.C. metropolitan areas. In Los Angeles, 43% of the women and 26% of the men had adjustable head restraints that were positioned properly; in Washington, D.C., these percentages were much lower (20% and 7%). After 25 years, a survey of cars in parking lots (O'Neill, 1999) indicated that more than half of the adjustable head restraints were left in the down position.

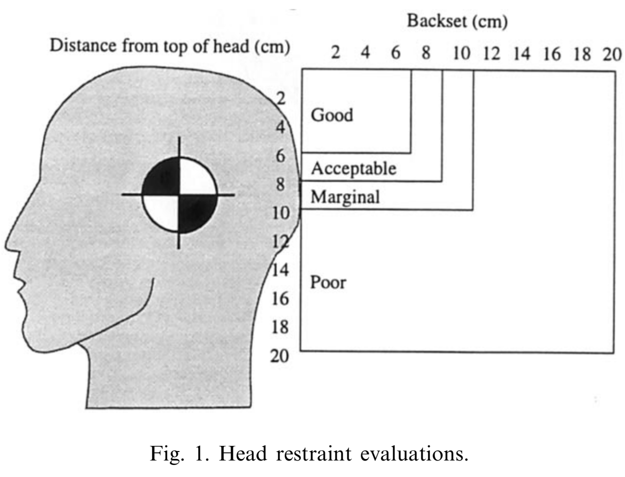

Fig. 1. Head restraint evaluations.

In 1994, an international ad hoc group of experts meeting in Lyon, France, recommended a minimum head restraint height in new cars that corresponded to the top of an average-size male's head. This would ensure that nearly all occupants could position the restraint behind the head's center of gravity, about 9 cm below the top of the head (University of Michigan Transportation Research Institute, 1983). The ad hoc committee also recommended that head restraints should be as close as possible to the back of the head. Olsson et al. (1990) demonstrated a significant increase in duration of neck discomfort (at least one year compared with less than one year) in relation to an increase in estimated horizontal distance (at least 10 cm versus less than 10 cm) between the backs of the heads and the head restraints of persons in rear-struck Volvos.

The head restraint geometry in a large number of recent model passenger vehicles has been evaluated using some of the committee's recommendations (Estep et al., 1995; Morris et al., 1998). Head restraints were rated good, acceptable, marginal, or poor based on their geometric measurements relative to an average-size male (Fig. 1). Adjustable restraints were measured in both their down and up positions, and if they lock in the up position, that was the basis for their rating. However, they were rated down one category because their adjustability reduces the likelihood they will be positioned correctly. Head restraints for only 5 out of the 164 cars (3%) tested in 1995 and 7 out of 247 vehicles (3%) tested in 1997 were rated good, and all of these were European cars with fixed head restraints.

Real-world evidence based on a random sample of more than 5000 rear-end collision insurance claims supports the hypothesis that in order for head restraints to be effective in preventing whiplash injuries they must have a good geometric design (Farmer et al., 1999). Property and personal injury claims from popular, recent-model passenger cars categorized as having good, acceptable, marginal, or poor head restraint designs (Estep et al., 1995) were examined for evidence of driver neck injuries. Overall, neck injury claims were significantly less frequent in vehicles with better-rated head restraints. Of drivers of vehicles with good head restraints, 22% claimed neck injury compared with 27% of drivers with poor head restraints. The effects were more pronounced for females than for males (23 vs 31% for females compared with 19 vs 23% for males). In this study it was not possible to directly evaluate whether the head restraints were adequately positioned for the individual drivers in the rear-end crashes. Rather, it could only be assumed that better geometric designs increased the number of drivers with adequately positioned head restraints.

The current study was designed to provide a direct assessment of whether properly positioned head restraints protect necks in rear-end crashes. Its design is similar to that of States et al. (1973), and data were collected in the same geographic area; however, it expands on this prior study in two major ways: by including an assessment of head restraint position with respect to the driver's head at the time of the crash and by providing an assessment of *each* vehicle's damage. It also specifically looks at the relationship between neck pain and human and environmental factors. The data were collected in Rochester, NY, one of a few states with verbal no-fault automobile insurance systems and thus less incentive to exaggerate soft-tissue injury claims (Carroll et al., 1995); therefore, self-reported neck injuries should be less likely to be exaggerated or falsely claimed.

2. Method

Between March 1, 1995, and June 30, 1997, files from each of 11 police agencies in Monroe County, NY, were reviewed on a weekly basis to identify all crashes in which one passenger vehicle was struck in the rear by another passenger vehicle. Crashes were considered pertinent when the struck vehicle was impacted only once and only in the rear. Crashes that were not considered included chain reaction type rear-end collisions or those in which the striking vehicle was rear-ended by backing into another vehicle (or fixed object). Location of the crash (e.g. intersection) and the type of traffic control (e.g. signal, stop sign, yield sign), when relevant, were determined from the crash reports. Information available in the crash reports led to contact with the drivers of the rear-struck vehicles. Drivers who agreed to participate in the study were interviewed by telephone to determine demographics, extent and nature of the injuries and/or symptoms attributed to the crash, and medical treatment received because of the crash. On-site inspections of the rear-struck vehicles were then scheduled at times and places convenient for the drivers.

Approximately 3500 crashes were identified as eligible for the study. During some weeks, contact was attempted for all eligible crashes. During others, the number of eligible crashes exceeded the time available to complete telephone interviews and on-site inspections, so a random sample of crashes was selected for attempted contact. Of the 2100 cases initiated, 75 were ruled ineligible either because the vehicle had been destroyed, sold, had no head restraint (e.g. in older pickups), or was otherwise not available for inspection. The remainder of the incomplete cases had drivers who refused to participate, could not be reached, or could not schedule on-site interviews within 30 days of the crash. Telephone interviews and on-site inspections were completed for 585 cases (28%), with telephone interviews being completed within two weeks to ensure recall of pain and treatment specifics.

During the on-site inspection, vertical and horizontal measurements of the driver's head relative to the head restraint were taken. Head restraint characteristics, whether fixed or adjustable and whether or not an adjustable head restraint was in its lowest position, were ascertained. Data were collected on the extent and nature of the vehicle's rear-end damage resulting from the crash. Visible/reported vehicle damage was standardized using the Vehicle Damage Scale for Traffic Accident Investigators, a set of photographs depicting extent of damage by type and location of impact, published by the National Safety Council (1984). This set of photographs was used to rate damage severity of each vehicle on a scale of 1–7, also known as the TAD scale, with 1 being minor and 7 being the most severe damage. When a vehicle was inspected prior to repair, pictures were taken as needed to capture images of rear-end damage. In cases in which damage had been repaired prior to inspection, the driver was asked to provide insurance or repair estimates and/or pictures if available. A vehicle that was considered totaled was inspected at the salvage yard as long as the seat back was intact and the driver could be seated in the vehicle for measurements and pictures. Although there was no explicit exclusion based on vehicle damage, the requirement of an intact seat back could have excluded a few very severe rear-end crashes.

Vertical and horizontal distances from the driver's head to the head restraint were made using a straightedge ruler fitted with a bubble level. The driver was instructed to sit in the vehicle on level ground in a normal driving position with the head restraint in the same position as at the time of the crash. Pictures were taken of the head restraint from the passenger side of the vehicle. Vertical distance was measured from a line level with the top of the driver's head to the top-front point on the head restraint. Horizontal distance was measured from the back of the driver's head to a point on the front of the head restraint on a level line (see Fig. 2). All measurements were recorded to the nearest quarter inch, but later converted to the nearest half centimeter for analytical purposes.

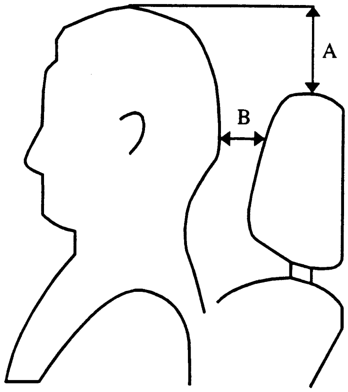

Fig. 2. Vertical and horizontal head restraint position.

The driver's head restraint position relative to the head was classified into one of four zones — good, acceptable, marginal, or poor — based on measured head restraint height and backset (Fig. 1). The border values for vertical height (6, 8, 10 cm) and horizontal backset (7, 9, 11 cm) were included with the lower, better zone. Categorization into one of the four zones did not depend on whether or not the head restraint was adjustable and, if adjustable, whether or not it was locked into position at the time of the crash; i.e. in the current study, it was the position of the head restraint relative to the driver's head and not the vehicle's head restraint geometry that was classified into zones. In addition, head restraint height and backset were categorized separately as good, acceptable, marginal, or poor. Backset was only considered appropriate for analysis if the driver had adequate vertical position (good, acceptable, or marginal — 10 cm or less from the top of the head).

Drivers were coded as reporting neck pain if in the telephone interview they reported minor, moderate, or severe neck pain attributed to the crash and lasting 1 day or more. The LOGISTIC procedure of the SAS computer software (SAS Institute, 1990) was used to model the likelihood of reported neck pain separately among female and male drivers as a function of vertical and horizontal distances of the driver's head from the head restraint. Vertical and horizontal distances were adjusted for statistically significant covariates. Potential covariates included the following: driver demographics including categorized age and actual height (measured) and weight (self-reported); vehicle characteristics including categorized and actual curb weight and wheelbase, vehicle type (passenger car/van versus other type of passenger vehicle), and design (domestic or import); and TAD scale crash severity. Simultaneous adjustment using all of the covariates would produce statistical problems related to multicollinearities. For example, vehicle curb weight and wheelbase are highly correlated with vehicle type and design. Therefore, a stepwise selection procedure was used to determine which covariates should remain in the model. Actual driver height and weight, actual vehicle curb weight and wheelbase, and vehicle type and design were not significant and thus were not used in the final models. Linear, quadratic, and cubic components of vertical and horizontal distances were included for testing in the models as appropriate. Because adjusted odds ratios (OR) derived from logistic regressions are not good approximations for adjusted relative risk ratios (RR) when the incidence of the outcome of interest is common in the study population (greater than 10%), as is true for neck pain, all odds ratios were transformed into relative risks as $RR = OR/[(1-P_0) + (P_0 \times OR)]$, where P_0 indicates the incidence of reported neck pain in the reference group (Zhang and Yu, 1998). For example, suppose an odds ratio of 0.40 comparing adequately positioned (in terms of vertical and horizontal positioning) with poorly positioned head restraints resulted from a logistic regression model adjusting for covariates and that 52% (P_0) of those with poor vertical and/or horizontal positioning reported neck pain. Transforming the odds ratio to relative risk, using participants with poorly positioned head restraints as the reference group, results in a relative risk of 0.58 — i.e. $RR = 0.40/[(1 - 0.52) + (0.52 \times 0.40)] = 0.58$. In other words, those with adequately positioned head restraints would be 42% (1−0.58) less likely to report neck pain. Note that in tables with statistics for vertical and horizontal zones the reference group was 'good' for each; the reference groups for curb weight and wheelbase were the lightest weight and shortest wheelbase, respectively. References for dichotomous variables are the second group in the comparison. For example, 'older' participants are the reference group in the comparison '< 50 years versus older.' Finally, the vehicle characteristics were obtained from the VINDICATOR computer software (Highway Loss Data Institute, 1997) using vehicle identification numbers.

Frequency tables were constructed to describe neck pain in relation to crash location and medical treatment. The distribution of neck pain according to head restraint height and backset and other characteristics significantly related to neck pain also is displayed. The distribution of head restraint characteristics (such as whether fixed or adjustable and whether or not an adjustable head restraint was in its lowest position at the time of the crash) is presented separately. In each table, the denominator (N) for each percentage is given.

3. Results

3.1. Medical treatment

Among the 585 rear-end collisions analyzed, there were 319 female drivers and 266 male drivers. Self-reported neck pain lasting 1 day or more was reported by 45% of female drivers, significantly higher than the 28% of male drivers (Table 1). Table 1 also shows that though the neck was the most common anatomical location for pain resulting from such crashes, 49% of female drivers and 33% of male drivers reported pain in other parts of the body. The parts of the body most affected included the head, shoulders, back and, to a lesser extent, upper extremities such as the hands. For more than 40% of female drivers, back pain was associated with neck pain. Similar results were found for head and shoulder pain. In fact, the majority of women and men with neck pain also reported pain elsewhere in the body.

One-quarter of female drivers sought medical attention; for those reporting neck pain, nearly half did so (Table 2). Male drivers sought medical attention to a lesser degree. Still, one-third of men with neck pain visited a doctor or medical facility. Of female drivers with neck pain 12% were examined at the hospital emergency room following the crash, whereas 36% did not seek medical attention until later. Though the same percentage of male drivers with neck pain received medical attention at the hospital, a lower percentage (22%), compared with female drivers, sought medical attention later.

3.2. Crash location

Neck pain percentages and corresponding sample sizes by crash location are given in Table 3. Just more than half (55%) of the rear-end collisions occurred at intersections. Of these, 81% (262 out of 322) had some sort of traffic control, 85% (223 out of 262) of which were traffic signals. Most of the nonintersection crashes resulted from vehicles stopped in the middle of the road because of congestion rather than from vehicles attempting to turn into driveways or parking lots. Other types of nonintersection crashes included drivers stopping for or trying to avoid debris or animals in the road. Of drivers in intersection crashes, 40% reported neck pain compared with 33% in nonintersection crashes.

3.3. Characteristics related to neck pain

Table 4 presents detailed neck pain percentages and corresponding sample sizes for several characteristics

Table 1
Percent of rear-struck drivers with pain by location of pain[a]

Location of pain	All participants		Participants with neck pain	
	Female drivers ($N = 319$)	Male drivers ($N = 266$)	Female drivers ($N = 142$)	Male drivers ($N = 75$)
Neck	45	28		
Head (includes orifices)	28	15	45	29
Shoulders	22	13	42	27
Back	26	18	43	31
Upper extremities	10	6	14	13
Chest	7	3	12	7
Abdomen	2	0	3	0
Hip	2	1	3	0
Lower extremities	5	4	8	9
Whole body	1	0	1	0
Other than neck	49	33	73	56

[a] Percentages total to more than 100% because each participant could have pain in more than one location.

Table 2
Distribution of rear-struck drivers by type of medical treatment

Medical treatment	All participants		Participants with neck pain	
	Female drivers ($N = 319$)	Male drivers ($N = 266$)	Female drivers ($N = 142$)	Male drivers ($N = 75$)
Hospital emergency room	6	4	12	12
General practitioner	13	7	25	15
Other (specialist, chiropractor, etc.)	6	2	11	7
No doctor visit	75	86	52	65

Table 3
Distribution and percent of rear-struck drivers with neck pain by crash location and circumstances

Crash location and circumstances	N	Percent of all participants	Percent with neck pain
Intersections			
No traffic control	60	10	43
Signal	223	38	39
Stop sign, yield, other	39	7	36
All	322	55	40
Nonintersections			
Turning	32	5	38
Congestion	200	34	33
Other	31	5	29
All	263	45	33

predictive of neck pain. Based on data from female drivers, all characteristics (grouped as indicated in the following text) entered the final model at the 0.05 level of significance using stepwise logistic regression. Female drivers younger than age 50 were significantly more likely than older female drivers to report neck pain, 47 vs 37%. Of female drivers in vehicles with visible or reported damage (TAD 1 +) 51% reported neck pain, significantly more than the 38% in vehicles with no visible or reported damage (TAD 0). A significant decrease in neck pain was found with increasing vehicle curb weight (from less than 2500 lb, up to 2500–3499 lbs, to 3500 lbs or more). A majority of the women in vehicles with wheelbases greater than 110 inches reported neck pain, leading to a significant increase in neck pain with increasing wheelbase. Though this may seem to be contradictory, i.e. one might expect the effect of wheelbase and weight to go in the same direction, the highest percentage of women with neck pain occurred in vehicles weighing 2500–3499 lbs (the middle weight category) with wheelbases greater than 110 inches. This group of vehicles had the lowest percentage of head restraints positioned behind the centers of gravity of the occupants' heads.

For male drivers, only damage severity was significant, with 19% of male drivers reporting neck pain when there was no visible damage to the vehicle versus 38% when there was some damage (Table 4).

Additional analyses showed that accounting for driver age, vehicle damage severity, curb weight, and wheelbase, female drivers had 1.54 ($P < 0.01$) times the risk of reporting neck pain compared with male drivers. After also accounting for whether or not the drivers' head restraints were positioned behind and close to their heads, this relative risk increased to 1.73 ($P < 0.01$). Driver age, vehicle damage severity, curb weight, and wheelbase also are accounted for in all subsequently presented relative risks.

3.4. Head restraint positioning

Head restraint positioning was significantly related to reported neck pain for female drivers but not male drivers. Tables 5 and 6 show, respectively, the percentages of female and male drivers with neck pain by composite, vertical, and horizontal head restraint zones, where composite zone is based on both vertical and horizontal distances. As shown in Table 6, only 28 men had adequately positioned head restraints with respect to both vertical and horizontal distances — too few to

Table 4
Percent of rear-struck drivers with neck pain by driver and vehicle characteristics[a]

Effect	Female drivers		Male drivers	
	N	%	N	%
Driver age (years)				
<30	34	47	41	34
30–49	196	47	139	26
50–64	60	40	48	29
≥65	29	31	38	29
Damage severity[b]				
0	166	38	135	19
1	91	54	67	34
2+	61	48	63	43
Vehicle curb weight (lb.)				
<2500	72	49	43	28
2500–3499	200	45	149	31
≥3500	47	38	74	23
Vehicle wheelbase (in.)				
≤100	63	43	50	28
101–105	112	42	92	32
106–110	72	44	43	26
>110	72	50	81	26

[a] For each effect there were 319 female and 266 male drivers, except for damage severity for which there was one driver missing for each gender.

[b] Damage severity is on a TAD scale of 1–7; 0 means no visible or reported damage.

Table 5
Percent of rear-struck female drivers with neck pain by composite, vertical, and horizontal zones

Head restraint zone	Composite		Vertical		Horizontal (excluding those with poor vertical zone)	
	N	%	*N*	%	*N*	%
Good	15	33	40	30	50	26
Acceptable	24	38	31	29	31	45
Marginal	70	26	72	29	28	18
Adequate (good, acceptable, marginal)	109	29	143	29	109	29
Poor	210	52	176	57	34	29

justify displaying detailed neck pain percentages for the three subcategories (good, acceptable, marginal). There also were too few men ($N = 36$) with adequate vertical head restraint positioning to justify displaying neck pain percentages for horizontal zones.

3.4.1. Vertical and horizontal zones (composite)

Table 7 lists all relative risks and statistical significances derived from logistic regression analyses of composite zone for female and male drivers. Females with adequately positioned (good, acceptable, and marginal categories combined) head restraints were significantly less likely to report neck pain (29%) than females with poorly positioned head restraints (52%) ($RR = 0.58$, $P < 0.01$).

Less than 11% of the men had adequately positioned head restraints; 18% of these men reported neck pain compared with 29% of the men with poorly positioned head restraints ($RR = 0.56$, $P = 0.16$). However, likely due to the insufficient sample size, this difference was not significant.

3.4.2. Vertical and horizontal zones (separate)

Using only vertical distances to determine the zones, women with vertical distances classified as poor (more than 10 cm) were at almost twice ($RR = 1.88$, $P < 0.01$, model not shown) the risk of reporting neck pain as women whose vertical distances were classified as adequate (combining good, acceptable, and marginal categories). Among female drivers with adequate vertical distances, there was no benefit of increased head restraint height, from good to acceptable and acceptable to marginal (Table 8). However, as shown in Fig. 3, reported neck pain increased as head restraint height further decreased among the poor head restraints (the trend, shown in Fig. 3, is statistically significant, $RR = 1.64$, $P < 0.01$). Neck pain was reported by 51% of those with poor head restraints no more than 7 cm below the head's center of gravity (no more than 16 cm below the top of the head) and 69% for those with lower head restraints approximately below the occiput (Fig. 3). Horizontal distance, ranging from good to poor, assessed only for those whose head restraints were high enough for backset to be relevant (i.e. vertical distance 10 cm or less), was not significantly related to neck pain (Table 8).

Table 8 shows that for women with adequate vertical head restraint measurements, damage severity and driver age were important in predicting neck pain. Vehicle curb weight and wheelbase did not appear to matter. For women who did not have adequately positioned head restraints with respect to vertical distance, vehicle curb weight and wheelbase were important predictors of neck pain, and to a lesser extent, so was the amount of damage (Table 8). Effects due to driver age were not remarkable.

There was an increasing trend of reported neck pain with increasing vertical restraint measurements for male drivers (22% with adequate vertical head restraint measurements, 27% with poor vertical head restraint measurements no more than 16 cm below the top of the head, and 31% with lower head restraints) (Fig. 3), but this was not significant ($RR = 1.26$, $P = 0.15$).

As mentioned previously, only 36 men had adequate vertical head restraint measurements, too few to meaningfully analyze the effects of backset and driver and vehicle characteristics (Table 6). However, Table 9 shows that men with poor vertical distances (at least 10 cm) were more than twice as likely to report neck pain if they had visible or reported vehicle damage compared with those who did not. Driver age and vehicle weight and wheelbase were not important in predicting neck pain for men.

Table 6
Percent of rear-struck male drivers with neck pain by composite and vertical zones

Head restraint zone	Composite[a]		Vertical[b]	
	N	%	*N*	%
Adequate (good, acceptable, marginal)	28	18	36	22
Poor	238	29	230	29

[a] Adequate composite zone: good ($N = 0$), acceptable ($N = 6$), marginal ($N = 22$).

[b] Adequate vertical zone: good ($N = 4$), acceptable ($N = 9$), marginal ($N = 23$).

Table 7
Relative risk of neck pain – composite zone[a]

Effect	Female drivers ($N=318$)		Male drivers ($N=265$)	
	Relative risk	P-value	Relative risk	P-value
Composite zone				
Adequately vs poorly positioned	0.58	<0.01	0.56	0.16
Driver age				
<50 years vs older	1.36	0.05	0.95	0.81
Damage severity				
TAD scale 1+vs. 0	1.39	0.01	2.10	<0.01
Vehicle curb weight				
Linear effect	0.72	0.02	0.87	0.56
Vehicle wheelbase				
Linear effect	1.21	0.04	0.99	0.91

[a] One female and one male driver had missing data. All statistical tests are two-tailed.

Table 8
Relative risk of neck pain for female drivers – adequate and poor vertical head restraint measurements[a]

Effect	Adequate ($N=143$)		Poor ($N=175$)	
	Relative risk	P-value	Relative risk	P-value
Vertical zone Linear effect	1.03	0.83	n/a	n/a
Horizontal zone Linear effect	0.93	0.58	n/a	n/a
Driver age				
<50 years vs older	1.89	0.06	1.15	0.36
Damage severity				
TAD scale 1+vs. 0	1.77	0.03	1.20	0.18
Vehicle curb weight				
Linear effect	1.01	0.96	0.67	0.02
Vehicle wheelbase				
Linear effect	1.05	0.80	1.20	0.01

[a] One driver with a poor vertical head restraint measurement had missing data. All statistical tests are two-tailed. n/a = not appropriate to include in model.

3.4.3. Fixed versus adjustable head restraints

Analyses related to head restraint characteristics are presented in Tables 10 and 11. Slightly more men than women drove vehicles with fixed head restraints (25 vs 18%) (Table 10). Though both men and women infrequently adjusted their adjustable head restraints, men were less apt than women to drive with their head restraints in the lowest position (64 vs 80%). This was particularly true for men driving import design vehicles, where 33% of their adjustable head restraints were left in the lowest position versus 62% for women. Table 11 shows for both women and men, fixed head restraints and adjustable head restraints moved up from the lowest position were more inclined to be adequately positioned behind the head's center of gravity.

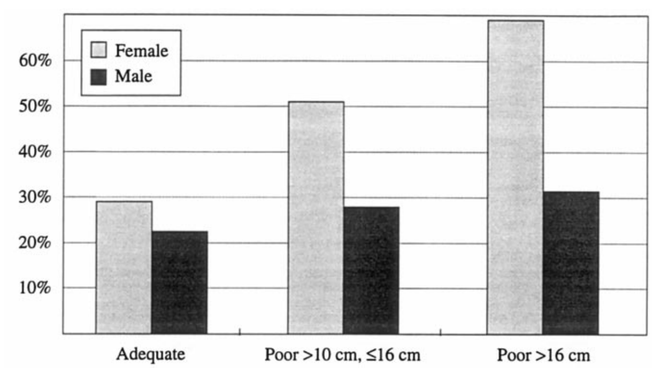

Fig. 3. Percent of rear-struck drivers with neck pain by vertical head restraint position.

Table 9
Relative risk of neck pain for male drivers – poor vertical head restraint measurements[a]

Effect	Poor ($N=229$)	
	Relative risk	P-value
Driver age		
<50 years vs. older	0.94	0.77
Damage severity		
TAD scale 1+ vs 0	2.30	<0.01
Vehicle curb weight		
Linear effect	0.77	0.31
Vehicle wheelbase		
Linear effect	1.05	0.74

[a] One driver had missing data. All statistical tests are two-tailed.

Table 10
Percent of rear-struck drivers with head restraint characteristic

Head restraint characteristic	Female drivers		Male drivers	
	N	%	*N*	%
Fixed	319	18	266	25
Not adjusted[a]	257	80	193	64
Domestic	186	87	130	78
Import	71	62	63	33

[a] Denominator is number of adjustable head restraints excluding unknowns.

Table 11
Percent of rear-struck drivers with adequate vertical head restraint measurements by head restraint characteristic

Head restraint characteristic	Female drivers		Male drivers	
	N	%	*N*	%
Fixed	56	54	66	18
Adjustable[a]				
All	263	43	200	12
Adjusted	51	59	70	24
Not adjusted	206	39	123	6

[a] Adjustment status was unknown for six female and seven male drivers.

4. Discussion

In this study, drivers of rear-struck vehicles involved in two-vehicle collisions with head restraints positioned adequately (i.e. no lower than the head's center of gravity and no farther behind the head than 11 cm) were less likely to report neck pain resulting from the crash than were those with poorly positioned head restraints. These results were statistically significant only for women, but the estimated effectiveness was similar for women and men (a 42 and 44% reduction in risk of neck pain, respectively). The small number of men with adequately positioned head restraints in the study meant that there was inadequate power to achieve statistical significance for this group.

The height of the head restraint was the primary factor related to head restraint effectiveness. Although not statistically significant for male drivers, the percentages of both female and male drivers reporting neck pain increased as the height of the head restraint further decreased below the head's center of gravity (Fig. 3). Among drivers with at least adequate head restraint height, there was no further benefit of increased height above the head's center of gravity, although this effect could be assessed only among women.

Horizontal distance from the head restraint, or backset, was not related to reported neck pain in this study. This may be because of the difficulty in reliably estimating the value of this parameter at the time of the crash, because asking drivers to sit in their vehicles as they would 'normally' may not always sufficiently replicate their position at the time of the crash. The vertical relationship between head and restraint is not as likely to vary each time people position themselves in vehicles because it is determined primarily by unchanging parameters such as seat stiffness and vertical head restraint adjustment, along with occupant height and weight. Horizontal distance, however, depends to a much greater extent on driver posture, especially on how much the driver leans forward or reclines the seat back, and a driver's normal seating posture and seat back angle may differ from that at the time of the crash. Thus, failure to find an effect of head restraint backset could be the result of an inability to reliably measure this parameter.

In the Olsson et al. (1990) study that first established a relationship between head restraint backset and neck pain, extensive investigations including crash reconstructions were used to determine the horizontal distance at the time of the crash, which may have led to more accurate estimates of backset. However, it must also be noted that the Olsson et al. study focused on long-term neck pain. In cases in which neck discomfort resulted from the crash, occupants with head restraint backsets 10 cm or more were significantly more likely than those with horizontal distances less than 10 cm to have neck discomfort for more than one year. It may be that initial reports of neck pain, such as those in the current study, can result even when backset is relatively minimal, but excessive backset leads to longer duration neck pain. This hypothesis could not be assessed with the current data.

The data do shed additional light on the issue of female and male differences in head restraint effectiveness. In the early 1970s, O'Neill et al. (1972) and States et al. (1973) found that women benefited more than men from having cars equipped with head restraints. Similarly, Farmer et al. (1999) found that head restraint designs that had been rated as having good or acceptable geometric position (relative to an average-size male) reduced the likelihood of neck injury insurance claims among female drivers in rear-end crashes, relative to poor head restraints. For men, however, only head restraints with good geometric designs appeared to reduce neck injury claims. It has been hypothesized, but not proven, that this apparent difference in the effectiveness of head restraints for women and men wasnot due to a real difference in the effect of head restraint position but rather to the fact that women are shorter on average than men; as a result, a given head restraint design is more apt to be positioned adequately for the average woman. The current study seems to support this notion: Although the statistical significance is stronger for women than for men, individuals at risk of neck pain, regardless of gender, reduced their risk by more than 40% with adequately positioned head restraints.

This does not mean that the risk of neck pain is similar for women and men or that the potential benefits of head restraints for the female and male populations are equivalent. Consistent with many previous studies (Schutt and Dohan, 1968; Kihlberg, 1969; O'Neill et al., 1972; States et al., 1973; Temming and Zobel, 1998; Farmer et al., 1999), female drivers were much more likely to report neck pain than male drivers even after taking relative head restraint positioning into account. The much higher rate of neck pain among women means that a greater percentage of women than men will benefit from adequately positioned head restraints, despite the equivalent reductions in risk that occur as a result of having adequate restraints. Perhaps equally important to note is that more women can benefit from proper positioning of adjustable head restraints in their current cars because their shorter stature permits even those restraints with poor geometric designs relative to the average-size male to be positioned adequately for them.

One seemingly contradictory result for female drivers was that as vehicle curb weight increased, neck pain decreased, but as wheelbase increased, neck pain increased. This result is primarily due to a particular group of vehicles in the middle weight category (2500–3499 lbs) with relatively long wheelbases, namely cars such as the Buick LeSabre and Oldsmobile 98 and Delta-88. These vehicles have adjustable head restraints with poor geometry that often were left in the down position. The vertical distance from the head of an average-size male to the head restraint in a 1997 Buick LeSabre, even in its highest position, is 15 cm. Of the women driving these Buick and Oldsmobile models 77% reported neck pain, most likely due to the poor geometry of the restraints rather than the increased wheelbases of the cars.

Though U.S. regulations mandate a minimum height of 27.5 inches above the seating reference point for head restraints in the highest position, there are no regulations governing a minimum height in the lowest position. Most vehicles in the United States have adjustable head restraints, and most individuals do not adjust them. Current European standards for head restraints in the lowest position exceed those of the United States for head restraints in the highest position. The most recent requirements adopted by the European Union in 1998 specify that head restraints should be at least 29.5 inches in the lowest position and exceed 31.5 inches in the highest position. In 1997, the American Automobile Manufacturers Association (since disbanded) and the Association of International Automobile Manufacturers petitioned NHTSA to upgrade U.S. head restraint requirements to be functionally equivalent to those of the European Union by 2004.

Women, and most likely men, in the United States would benefit greatly from international harmonization to European head restraint standards. Until then, both women and men should be encouraged to adjust their adjustable head restraints, if possible, behind their heads' centers of gravity and to sit with the backs of their heads as close as possible to their head restraints.

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References

Carroll, S., Abrahamse, A., Viana, M., 1995. The costs of excess medical claims for automobile personal injuries. RAND Corporation, Santa Monica, CA.

Estep, C.R., Lund, A.K., Vann, D.T., 1995. Measurement and evaluation of head restraints in 1995 vehicles. Insurance Institute for Highway Safety, Arlington, VA.

Farmer, C.M., Wells, J.K., Werner, J.V., 1999. Relationship of head restraint positioning to driver neck injury in rear-end crashes. Accident Analysis & Prevention 31, 719–728.

Highway Loss Data Institute, 1997. VINDICATOR User's Manual, VINDICATOR 98 – Release No. 1. Arlington, VA.

Insurance Research Council, 1994. Auto injuries: claiming behavior and its impact on insurance costs pp. 21, 22, 38. Oak Brook, IL.

Kahane, C., 1982. An evaluation of head restraints, Federal Motor Vehicle Safety Standard 202. Report DOT HS-806-108. U.S. Department of Transportation, Washington, DC.

Kihlberg, J.K., 1969. Flexion-torsion neck injury in rear impacts. Report CAL-VJ-2721-R2, 1-3. Cornell Aeronautical Laboratory, Inc., Buffalo, NY.

Morris, C.R., Lund, A.K., Vann, D.T., 1998. Measurement and evaluation of head restraints in 1997 vehicles: procedures and detailed results. Insurance Institute for Highway Safety, Arlington, VA.

National Highway Traffic Safety Administration, 1996. Head restraints – identification of issues relevant to regulation, design, and effectiveness. Submitted to NHTSA Docket No. 96-22, Notice 1-01, November 4, 1996. U.S. Department of Transportation, Washington, DC.

National Safety Council, 1984. Vehicle damage scale for traffic accident investigators. Revised with the assistance of University of North Carolina Highway Safety Research Center. Washington, DC.

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. Proceedings of the 1990 International IRCOBI Conference on the Biomechanics of Impacts, IRCOBI, Lyon, France, pp. 269–280.

O'Neill, B., 1999. Head restraints – the neglected countermeasure. Accident Analysis & Prevention, 32, 143–150.

O'Neill, B., Kelley, A.B., Sorenson, W.W., Haddon, W. Jr., 1972. Automobile head restraints – frequency of neck injury claims in relation to the presence of head restraints. American Journal of Public Health 62, 399–406.

Ruedemann, A.D., 1957. Automobile safety device – head rest to prevent whiplash injury. Journal of the American Medical Association 164, 1189.

SAS Institute Inc., 1990. SAS/STAT User's Guide, Ver. 6, 4th Ed. Cary, NC.

Schutt, C.H., Dohan, F.C., 1968. Neck injuries to women in auto accidents. Journal of the American Medical Association 206, 2689–2692.

States, J.D., Balcerak, J.C., Williams, J.S., Morris, A.T., Babcock, W., Polvino, R., Riger, P., Dawley, R.E., 1973. Injury frequency and head restraint effectiveness in rear-end impact accidents. Proceedings of the 16th Stapp Car Crash Conference. Society of Automotive Engineers, New York, NY, pp. 228–257.

Temming, J., Zobel, R., 1998. Frequency and risk of cervical spine distortion injuries in passenger car accidents: significance of human factors data. Proceedings of the 1998 International IRCOBI Conference on the Biomechanics of Impacts. IRCOBI, Lyon, France, pp. 219–233.

University of Michigan Transportation Research Institute. 1983. Anthropometric specifications for mid-sized male dummy (side view with skeleton). Drawing Number NM-104. Ann Arbor, MI.

Zhang, J., Yu, K., 1998. What's the relative risk? A method of correcting the odds ratio in cohort studies of common outcomes. Journal of the American Medical Association 280, 1690–1691.