ABSTRACT

This paper presents the results of studies conducted in Delhi, India, on the pattern of motorized-two-wheeler and helmet use patterns, injuries to two-wheeler crash victims hospitalised in a neurosurgery ward, police reported fatal crashes and biomechanical evaluation of crash involved motorcycle helmets. The results indicate that in the absence of a law education alone does not convince riders to use helmets in Delhi and that lack of driver training does not seem to be a factor contributing to serious injury and fatal crashes. Conspicuity and better helmet design are the two most important safety measures for motorcycle and scooter riders.

INTRODUCTION

The production of motorized-two-wheelers (MTWs) in India has increased more than five-fold in the last decade whereas that for automobiles has not even doubled. In the city of Delhi there are almost three times as many MTWs registered as automobiles and there is a large variation in the masses and velocities of the various vehicles plying on the road. These vehicles include trucks, buses, three-wheeler motorcycle taxis, minibuses and trucks, hand carts, animal drawn vehicles, bicycle rickshas and bicycles. These factors result in MTWs comprising 16% (107) of all traffic fatalities in Delhi in 1980. Pedestrians accounted for 33%, bicyclists 21%, and all motorised 3 and 4 wheelers 10% (not including bus commuters). This shows that among motor vehicle occupants MTW riders constitute a vast majority of crash fatalities in Delhi. This situation is likely to worsen because in India the rate of increase of production of MTWs is much higher than that of automobiles.

The Centre for Biomedical Engineering has been involved in studying the MTW crash problem in all its aspects. Studies have been conducted on the
pattern of MTW and helmet use in Delhi (1), injuries to two-wheeler crash victims hospitalised in a neurosurgery ward (2), fatal crashes in Delhi (3), and biomechanical evaluation of motorcycle helmets in use in India. This paper presents the main results of our investigations over the past four years.

METHODS

The details of the methodology used to determine patterns of MTW and helmet use, epidemiology of hospitalized MTW crash victims and fatal crash victims have been given elsewhere (1-3). Use pattern data were obtained by observing 12,730 riders on the roads of Delhi, injury details from a study conducted on 72 MTW crash victims admitted over a one year period to the neurosurgery ward of the All India Institute of Medical Sciences, and fatal crash information from data recorded by the Delhi Police for 107 fatalities over one year. An additional fifty fatal crash reports were analyzed in detail to study the crash patterns.

Crash involved helmets were obtained from victims by giving them brand new helmets (donated for the purpose by a local manufacturer) in exchange. The damage to the helmet was documented and its role in the crash assessed by determining as best as we could whether the straps were tied before the crash, the location of the helmet after the crash and the head injuries sustained by the rider.

To evaluate the mechanical characteristics of crash involved helmets the following measurements and tests were performed:

1. Type of shell material and its thickness
2. Thickness of the liner (if present) on the left, right, front, back and top of the helmet.
3. A circular plug (30 mm diameter) of the liner was cut out with a coring tool from an undeformed area. The dimensions and mass of the plug were recorded and then the plug tested in compression on an Instron Universal Testing Machine.

In order to determine the properties of such helmets in an undamaged state, brand new helmets of different brands were purchased and the following tests performed:

1. Force deflection characteristics (quasi-static) by testing the helmet in compression using a wooden headform in inferior-superior, left-right and anterior-posterior directions.
2. 30 mm diameter plugs were obtained from undeformed liners and their densities, dimensions and force-deflection characteristics in
The properties of used helmets were assumed to be similar to those new helmets where the shell thickness and liner plug dimensions and force-deflection properties were similar.

RESULTS

Use Patterns:

In the Union Territory of Delhi only drivers of MTWs are required to wear a helmet by law but all Sikhs and passengers are exempted. We estimate that as a result only 61% of the MTW riders are covered by the law and 48% end up using helmets which are properly strapped. Chin-cups are still widely used (59% of strapped helmets) and so it may be assumed that only 20% of all riders are adequately protected. Therefore it is not easy to detect influence of the helmet law by examining fatality statistics alone.

Our survey indicated that 93% of those wearing helmets used the jet type and less than 1% full-face type. This is largely because full-face helmets are 2 to 5 times more expensive than jet-type and they are also very uncomfortable in tropical climates. Compliance of the law varied from 80% on main roads in day time to 40% in residential areas at night. Virtually none of the passengers were observed to be wearing helmets in spite of the publicity given to the protective value of helmets. This shows the inadequacy of education in the absence of a law mandating helmet use.

Crash Patterns:

MTW traffic volume drops considerably soon after the evening rush hour and is almost negligible by midnight. But crashes between sunset and sunrise constituted at least 40% of both the fatal crash and hospitalized samples.

Impact site, crash type and crash location for the hospitalized samples and fatal crashes is shown in Table 1.

These data show that crash patterns are similar for the hospitalized and fatal crash samples except for single vehicle crashes. A majority of the fatal crashes involve heavy vehicles like buses and trucks whereas in the hospitalized sample almost half the crashes did not involve any other vehicle. This is probably due to the fact that MTWs are used mainly by working males for commuting and family needs and not for sporting purposes. Therefore vehicle velocities are relatively low and single vehicle crashes are less likely to result in a fatality. Whereas, fatal injuries are more likely to be produced when MTW riders are hit by large vehicles like trucks and buses.
TABLE 1

<table>
<thead>
<tr>
<th>Crash Details</th>
<th>Hospitalized Sample</th>
<th>Fatal crashes only</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Hit from rear</td>
<td>40%</td>
<td>57%</td>
</tr>
<tr>
<td>Hit from side</td>
<td>16%</td>
<td>14%</td>
</tr>
<tr>
<td>Hit from front</td>
<td>44%</td>
<td>29%</td>
</tr>
<tr>
<td>2. Hit by automobiles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>trucks and buses</td>
<td>12%</td>
<td>13%</td>
</tr>
<tr>
<td>other</td>
<td>15%</td>
<td>69%</td>
</tr>
<tr>
<td>Single vehicle</td>
<td>25%</td>
<td>13%</td>
</tr>
<tr>
<td>3. On straight roads</td>
<td>48%</td>
<td>71%</td>
</tr>
<tr>
<td>At intersections</td>
<td>14%</td>
<td>29%</td>
</tr>
</tbody>
</table>

CRASH DETAILS OF MTW RIDERS HOSPITALIZED IN A NEUROSURGERY WARD AND FATAL CRASHES RECORDED BY THE POLICE. PERCENTAGES ARE BASED ON SAMPLES WHERE DETAILS WERE AVAILABLE.

Human Factors:

54% of MTW riders in the fatal sample and 47% in the hospitalized group were over 30 years old. Among the hospitalized group 29% admitted having consumed alcohol before the crash and only 3% had less than two years experience. These data were not available for the fatal crash sample. No breath/blood alcohol test were conducted. This indicates that alcohol involvement in crashes, especially at night is quite high considering the fact that details of other vehicle drivers were not available.

Injuries:

Injury details (reliable) were not available for the fatal crash sample. Head injury severity of hospitalized riders is shown in Table 2 and location of skull fractures in Table 3.

Figures 1 and 2 show the locations of superficial injuries sustained by unhelmeted and helmeted (claimed) riders respectively. These data show that the crown of the head sustained no superficial injuries in both the unhelmeted and the helmeted cases, however this is the area where the helmet is designed to give the maximum protection. None of the riders sustained a puncture wound by a sharp object but helmet standards in most countries including India incorporate a penetration test providing protection against punctures by sharp pointed objects. Eleven (30%) of the riders claiming helmet use sustained superficial injuries in areas which are expected
Figure 1. LOCATIONS OF SUPERFICIAL INJURIES TO UNHELMETED MOTORIZED TWO-WHEELER RIDERS HOSPITALISED IN A NEUROSURGERY WARD
Figure 2. LOCATIONS OF SUPERFICIAL INJURIES TO HELMETED (CLAIMED) TWO-WHEELER RIDERS HOSPITALISED IN A NEUROSURGERY WARD
TABLE 2

<table>
<thead>
<tr>
<th>AIS SCORE</th>
<th>HELMET USE (CLAIMED)</th>
<th>NO HELMET</th>
<th>HELMET USE UNKNOWN</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>D</td>
<td>E</td>
<td>N</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>4</td>
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<td>3</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>6</td>
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<tr>
<td>4</td>
<td>9</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

22 4 3 17 13 9 2 2 72 (101%)

N - No Neurological deficit  D - Neurological deficit  E - Expired

HEAD INJURY SEVERITY OF RIDERS HOSPITALIZED IN A NEUROSURGERY WARD CLASSIFIED BY OUTCOME AND HELMET USE.

TABLE 3

<table>
<thead>
<tr>
<th>Location of Skull fracture</th>
<th>Number of Fractures*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>helmet used (claimed)</td>
</tr>
<tr>
<td></td>
<td>11 riders</td>
</tr>
</tbody>
</table>

Frontal 2 5 -
Parietal 4 12 1
Temporal 5 7 1
Occipital - 7 -
Base 5 3 2

*Single fractures of multiple bones are listed under each bone e.g. a fracture extending from the temporal bone to the parietal bone will be listed under both parietal and temporal.

LOCATION OF SKULL FRACTURES OF CRASH VICTIMS HOSPITALIZED IN A NEUROSURGERY WARD.

to be covered by the helmet. This indicates that at the time of impact the helmet was no longer on the head or had rotated away.
The right side of face sustained a larger number of injuries than the left side. We do not know whether this is an artifact of this sample as no other data on location of facial injuries have been published in India. Some have suggested that this may be due to the fact the vehicles drive on the left of the road in India. It would be interesting to compare this with data from countries where traffic drives on the right.

Effect of Helmet Use:

The police report data were not considered accurate enough for judging effect of helmet use and only the hospital based data were used for this purpose. Out of a total of 72 riders only 29 (40%) claimed helmet use and of these 13 admitted not fastening the helmet straps. Therefore it is not surprising that at least 11 riders sustained superficial injuries in areas that should normally have been protected by helmets. However only 24% of those who claimed helmet use sustained head injuries with severity of AIS 5 whereas the figure for unhelmeted riders was 55% and the figures for neurological deficit were 14% and 33% respectively.

Crash involved helmets were obtained in nineteen cases and for these an attempt was made to judge the effect of helmet use on head injury by examining damage to the helmet, known crash details and injuries sustained. Of the seven cases with AIS 5 only 5 were judged to have had their helmets on their heads during impact. Only 1 of these five suffered skull fracture. In 4 or the 5 cases the impact was on the edge of the liner. There were 4 cases with AIS 4 of which at least one did not appear to have the helmet on the head at the time of impact. In another two cases the impact was below the edge of the liner. In a majority of the other cases where the injury was of AIS 3 or lower, the impact was at the edge of the liner or lower. This indicates that it is very important that the area covered by the liner should be much more and extend as low as possible to cover the sides of the head and face. In those cases where we judged the helmet not to have been on the head during impact we could not determine whether this was due to a fault in the retention system or that the strap was not tied at all.

Because of the small sample it is not possible to do a statistical analysis to evaluate the protective benefits of helmets. However, the data give clear qualitative evidence that almost any helmet when used properly does provide protection to motorcyclists.

Helmet properties:

Nineteen helmets were obtained from crash involved MTW riders who were admitted to the hospital. The damage to these helmets were recorded and are shown in Figure 3. In most cases the damage is on the sides and not on the crown of the helmet. Here again there are more impacts on the right side than on the left. All the helmet shells were made of fibreglass with
Figure 3. LOCATION OF DAMAGE TO NINETEEN CRASH INVOLVED HELMETS OBTAINED FROM RIDERS ADMITTED TO A NEUROSURGERY WARD
thickness of most varying from 2.5mm and 3.5mm. All had polystyrene liners with thickness ranging from 10mm to 25mm. Within each helmet the liner thickness could vary by 2-6mm with the crown being the thickest.

The density of plugs cored out from undeformed parts of the polystyrene liners varied from $1.9 \times 10^{-5}$ to $3.5 \times 10^{-5}$ kg/m$^3$.

Two brands of new helmets representing the thin and the thick liner and shell material were tested in compression using a wooden headform on an Instron Testing Machine at quasi-static strain rates. These helmets represent the two ends of the range of helmets obtained in the study. This was ascertained by comparing the density and thickness of liner materials of these helmets. The force deflection curves for these helmets are shown in Figure 4.

These curves show that the Indian helmet with the stiffer and thicker liner (helmet E in Figure 4) is 'softer' than the U.S. made Bell helmet. Helmet E is two to three time more expensive than the most commonly used helmets of type S. The latter is much softer and the liner "bottoms out" at loads around $8 \times 10^3$ Newtons in SI direction and less than $2 \times 10^3$ Newtons in the L-R direction. Indian helmet E can tolerate at least twice these loads in both directions and the Bell helmet almost three times in the SI direction.

**DISCUSSION**

The traffic patterns in Delhi are very different from most metropolitan cities in high-income industrialised countries mainly because of the large variety of vehicle types present on the road and the differences in their masses and velocities. Riding speeds are also affected because majority of MTW riders in Delhi are in general older than MTW riders in Europe and the U.S.A. and they do not use their vehicles for sporting purposes. Studies from high-income countries (5, 6) report that a very large number of MTW riders have less than 1 year's experience whereas only 2 out of 72 of the crash victims in our sample of hospitalized riders reported driving experience of less than two years. This suggests that driver education may not effect MTW fatality and serious injury rates in Delhi. This may also account for the lower percentage of single vehicle crashes. Therefore in Delhi more attention would have to be given to reducing conflict between MTWs and high mass vehicles like buses and trucks.

For some time the curbside lane was reserved for buses on many roads in Delhi but this was not successful partly because the very slow vehicles (animal or human powered) also used these lanes. This practise has now been virtually given up. Some other innovative ways of traffic management have to be developed to separate traffic. Further restrictions on truck movement and heavy vehicle speeds would be advisable.
Figure 4. QUASI-STATIC LOAD DISPLACEMENT CURVES FOR ONE U.S. MADE (BELL) AND TWO INDIAN (E & S) HELMETS (U.S. DATA FROM REFERENCE 4)
A large proportion of riders, both in the fatal and the hospitalized sample were hit on the straight road and not at intersections, especially at night. In both samples more than 40% were hit from the rear. The proportions are much higher than reported in most other studies (5, 7-9). Crash details recorded in the police reports and those given by the hospitalized riders suggest that inconspicuity of the rider and motorcycle may be a serious problem as many streets are not well lit. Because of the tropical weather conditions it is not possible for riders to wear bright coloured jackets like the ones worn in colder climates all the year around. Therefore it is very important for the MTWs and the helmets to be made much more conspicuous.

A study conducted at the Centre for Biomedical Engineering (10) shows that given the lighting conditions in Delhi at night and the bright sunlight in the daytime there are only two colours – bright yellow and orange – which are conspicuous at all times. Therefore we suggest that all MTWs and helmets should be painted only in these two colours and their conspicuity further enhanced by use of reflectors and bigger head and tail lamps.

Head injury data and helmet analysis quite clearly indicate that though the sides of the head are most vulnerable it is the crown of the helmet which has been designed to provide maximum protection. Even the most expensive Indian helmets have liners which are far too soft especially in the L-R direction. However, our results indicate that even the cheapest helmets available in India do provide some protection. The degree of protection can be improved by helmet liners extending much further down on the sides of the head and with stiffer compression properties. These properties can be optimised given the maximum thickness allowable and for velocities at which maximum protection is needed. Serious thought should be given to the advisability of retaining the present helmet penetration standard. Helmets also have to be developed with much better side protection without the discomfort perceived by wearers in tropical climates.

This study also showed that some riders sustained serious head injuries in falls in single vehicle crashes at estimated velocities as low as 15 kmph. Some of these riders included Sikhs who are exempted from wearing helmets as their religion requires them to wear turbans. Some Sikhs believe that turbans provide some protection but our study showed no evidence of this.

MTW use is growing rapidly in lower income countries and safety counter measures specifically suited to local conditions have to be evolved. Our experience in Delhi suggests that conspicuity and better helmet design are the most important issues facing us. However, it would certainly be much more efficient if MTWs are phased out by providing more efficient and comfortable public transportation.

ACKNOWLEDGEMENT

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