

HOW DO MOTORCYCLE HELMETS AFFECT VISION AND HEARING

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SUMMARY

While helmets are known to reduce the chances of head injury in a motorcycle accident there is concern that they might increase the possibility of a crash by interfering with the rider's vision and hearing. This study measured the effects of motorcycle helmets upon both seeing and hearing by having 50 riders operate over a test route, changing lanes in response to a sound signal under three helmet conditions: none, partial coverage, and full coverage. Half of the riders were assessed for the degree of head rotation during the lane changes, while the other half were assessed for the decibel level at which they first responded to a sound signal. Results showed that riders in the vision study increased the degree of head rotation in proportion to the vision restriction imposed by the helmets. While, the degree of rotation did not entirely match the full extent of the restriction, individual differences in head rotation far exceeded the effect of variation in helmets. Riders in the hearing study evidenced no differences in the sound level at which the sound was detected across the three helmet conditions. It is apparent that the effects of helmets upon the ability to see and hear are, at most, far too small to compromise the safety benefits offered by head protection.

INTRODUCTION

The possible effect of motorcycle helmets upon hearing and hearing has been raised by some riders as an argument against helmet use. Some riders claim that a helmet blocks the sounds of overtaking cars, police, or ambulances. Others claim that helmets restrict the field of view, making it less likely that riders will notice other vehicles when changing lanes. Motorcycle crash statistics establish conclusive evidence that, helmets reduce the likelihood of death and serious injury in an accident (Evans & Frick, 1988; Wilson, 1989). The reduction in deaths brought about by wearing helmets is estimated at about 25%. It is largely on the basis of this finding that many States have enacted mandatory helmet legislation. However, if helmets were to have the effects upon vision and hearing that some claim, they could negate the protection they provide in an accident by increasing chances of an accident occurring.

Research into the effects of helmets upon the two processes of hearing and hearing has been carried out by different sets of investigators using entirely different methodologies. The two are therefore best discussed separately.

Research on Hearing

Of the two possible effects of helmet use, effects upon hearing have been the more extensively studied. Back in 1975, Henderson pointed out that the motorcycle engine and air turbulence produce a "masking" noise and that other sounds would have to be louder than the masking noise if they are to be heard. He noted that any sound loud enough to be heard without a helmet should also be heard with a helmet, which reduce both noises equally. Harrison in 1973 measured sound pressure in the ear of riders and found that helmets reduced masking noise at high speeds. Van Moorhem, Shepherd, Magleby and Torian (1977), used microphones placed in the ears of riders wearing helmets to measure the noise generated while either operating a motorcycle or riding in a convertible car. They concluded that a rider is never at a disadvantage while wearing a helmet, and at increased speeds wearing a helmet may be advantageous in the detection of a warning signal. Aldman, Gustaffson, Nygren and Wersall (1983) measured sound pressure in the ear with and without helmets and found that detection of signals would not be hampered by the wearing of helmets. They also concluded that helmets may provide protection from hearing damage caused by noise. Satsangi (1979) measured the amount of noise created by different helmets and face shields and found noise was greater without helmets. Purswell and Dorris (1977) found that wearing helmets affected the ability of subjects to perceive an audible signal. However subjects in that study were seated on stationary motorcycles, so that air turbulence, which accounts for over half of the noise heard by a rider when riding at moderate or faster speeds, (Van Moorhem et al., 1977; Aldman et al., 1983) was not taken into account.

Research on Vision

Gordon and Prince (1975) studied the effects of helmets on the field of view. Riders either wore one of two types of helmets — three-quarter coverage or full — or did not wear a helmet at all. An object moved along a track toward the center of the subject's vision from ten different directions and the riders identified the point at which they first recognized it. Those riders wearing the three-quarter coverage helmet lost about 3% (6.5E) of the horizontal plane while those wearing various full coverage helmets lost from 7.3% (16.9E) to 21.9% (51.7E). Hurt (1979), in reviewing motorcycle accidents, concluded that most of the hazards that a rider must avoid come from the front. McKnight, McPherson, and Knipper (1980) analyzed Hurt's data for the actual causes and concluded that 11% of the accidents were related to the rider's field of view. However, it was impossible to tell from the data how many if any of these accidents involved impairment caused by helmets.

There is little question as to the restriction in peripheral vision imposed by the structure of motorcycle helmets so long as the head remains stationary. However, the head is capable of turning. The effect of helmets upon visual search when stopped at intersections should be negligible since riders have time to turn their heads as far as needed to see vehicles or pedestrians approaching from either direction. However when changing direction on the fly, as in merges and lane changes, looking to the side and rear necessitates a diversion of attention which may encourage skimming on head turn. Here, the visual restriction of a motorcycle helmet could spell the difference between seeing and not seeing an adjacent or overtaking vehicle.

Research Objective

The objective of this study was to assess the effect of wearing a helmet upon hearing and hearing in the normal highway traffic environment. Specifically, the study assessed the ability of motorcycle operators to (1) detect sounds when operating under conditions of engine noise and air turbulence that arise at normal highway speeds, and (2) to see vehicles in adjacent lanes prior to initiating lane changes. In both cases, the riders were not to know the purpose of the study to keep study conditions from influencing their normal riding behavior.

METHODS

To measure the effects of helmets upon vision and hearing, samples of riders rode their own motorcycles along a test route, making periodic lane changes in response to an audible signal from a following vehicle. The route was driven three times, with three degrees of helmet coverage: *None* — No motorcycle helmet, *Partial* — Three-quarter coverage helmet (HJC Model FG-3S), and *Full* — Full face coverage helmet (HJC Model FG-6). In the study of hearing, the level of a sound signal was changed systematically to discover the lowest volume under which it could be detected with each of the three types of helmet. In the study of vision, the degree of helmet rotation during lane changes was measured through on-board instrumentation.

To keep riders from being unduly influenced by knowledge of what was being measured, those taking part in the hearing experiment were told that their head rotation was being measured, while those in the vision study were told that their hearing was being measured. Each run under each helmet type took place at 30 mph over one half of the route, and 50 mph over the other half, the order of speeds being reversed from one run to another to keep the order from influencing any effects of speed.

Helmets and hearing

The ability to hear was measure by changing the decibel levels of sound signals and recording the lowest level at which riders responded. Test administrators followed behind the motorcycle in an automobile and activated the sound signal. Riders were told that when they heard the signal, they should turn their heads slowly until they could just see the test administrator's vehicle in the corner of the eye. The strength of the signal was systematically increased until riders turned their heads. Riders were instructed to change lanes after each trial so that another trial could be performed in the opposite direction. One administrator operated the test vehicle while the other monitored traffic to the rear and activated the signals, which were never given if a vehicle was observed to be overtaking in an adjacent lane (riders were not told this since it might have altered the responses being measured).

It was not possible to measure the actual sound energy at the motorcycle since any sensing device would experience the same masking effects of engine noise and air turbulence as would the rider. Rather, it was necessary to (1) measure separately the decibel level of the sound

signal at various distances from its source, and (2) estimate the distance over which sound had to travel on each trial. The sound signal was a steady 700 cps tone generated by a siren driver designed for home alarm systems. Signal strength at various distances from the source were measured in advance with the aid of a decibel meter. Varying distances were needed in order to be further from riders when they were traveling slowly and could hear fairly well, and closer when they were traveling faster and had difficulty hearing. In pre-trial experiments, the decibel level at any distance from the sound source was equal to the expression:

$$(1) \text{ db SUB h} = 1.07 \text{ db SUB s} + (1473 / D \text{ SUP } 2) - 19.8$$

where db_h = decibel level of the sound signal at the helmet, db_s = decibel level of sound signal at the source, and D = distance over which sound travels on a particular trial.

In measuring distance to the motorcycle, radar or laser distance measuring equipment made unsuitable by the small target provided by the motorcycle. Instead, a video camera mounted atop the vehicle allowed headway to be measured to within 1/30th of a second by counting the number of frames between the point at which the motorcycle and automobile passed a landmark and knowing the speed of the vehicles at that instant. The distance over which sound traveled on a trial (d) equaled the headway (distance between vehicles) plus the distance the motorcycle traveled between activation of the signal and the sound reaching the helmet, as given by the expression

$$(2) d \sim = \sim h \sim + \sim h (s \text{ SUB } v \sim / (s \text{ SUB } s - s \text{ SUB } v))$$

where: h = headway, s_s = speed of sound at sea level (1,088 fps), and s_v = speed of the vehicles.

Vision

The measure of vision was the degree of head rotation to either side prior to initiating the lane change. Riders were told that when they heard the sound signal, they were to indicate it by initiating a lane change as soon as it was safe to do so. They were reminded that since testing was taking place in traffic, it was important to check over their shoulder for the presence of other vehicles prior to changing lanes. In the vision study, it was necessary to use a bicycle helmet as the "no-helmet" in order to provide a surface upon which to place the markings needed to measure the degree of subject head rotation. This helmet introduced no restriction to peripheral vision. Since riders in the vision study were told that their hearing was being measured, the bicycle helmet was explained as being a way to provide protection while not affecting hearing.

Two aspects of vision defined the relationship with vision: the visual restriction imposed by the helmet, and the degree of head rotation required to make up for the restriction. Vision restrictions imposed by each of the two helmets were measured by determining the visual angle at which an object to the side could be detected. Compared with the no helmet condition, the partial coverage helmet reduced vision to the side by between 20E and 30E, depending on the riders' facial structures, while the full coverage helmet reduced it by between 13E and 18E. With the particular helmets employed in the study, the aperture provided by the full coverage helmet

actually permitted a wider visual angle than did the partial coverage helmet.

The means by which head rotation was measured during lane changes could not be allowed to interfere with or influence in any way with head rotation itself, eliminating the use of mechanical contrivances affixed to the helmet. Instead, head rotation was measured by means of a small VHS-C camcorder, mounted in a box secured to the seat behind the operator to record a close-up of the back of the rider's head. The top and front of the box were covered with a sheet of mirrored plastic film that made it nearly impossible for the rider to see into the box, explained as "sound recording equipment."

To allow the degree of head rotation to be measured, the base of the helmet was marked off in 5E intervals. As noted earlier, "unhelmeted" riders wore a small bicycle helmet, which imposed no visual restrictions but could be graduated with the same markings as the helmets. A series of trials in which raters recorded degrees of head turn from a videotape for which the actual degree of turn was known, showed that it was possible to measure orientation of the helmet to within $\pm 2.5E$ in all cases. The time to complete a visual check was obtained by counting the number of video frames from the start of head rotation in the direction of lane change to the end of head rotation in the return direction.

Riders

A total of 50 riders took part in the study — 25 in the hearing study, and 25 in the vision study. Riders furnished their own motorcycles in order to keep any practice effect from being confounded with helmet condition. Mechanical problems resulted in loss of data from one of the hearing riders and two of the vision riders, reducing the sample sizes to 24 and 23 respectively. Age and years of riding experience are shown in Table 1.

Table 1
Age and Experience of Subjects

Study	Age			Experience		
	Min	Max	Mn.	Min	Ma	Mn.
Hearing	21	52	28	2	32	8
Vision	21	52	28	2	32	7

All riders had valid drivers licenses and 20/40 corrected visual acuity or better. The requirements of the studies were described to all riders during the recruitment phase. Any prospective rider who admitted having any visual or hearing difficulties was not allowed to participate in the study. To qualify for the study, riders had to be experienced operating both with and without a helmet. Since the study was conducted in Maryland, at that time a non-helmet law State surrounded by States with mandatory helmet legislation, this condition was not difficult to meet.

Procedures

When riders arrived for testing, they completed a pre-test questionnaire and received instructions on how the study was to be conducted. Each rider then operated three times over a prescribed test route 5.5 miles in length. The route consisted of a four-lane divided highway posted at 50 mph. Each trial involved a round trip, i.e., out and back. Riders were instructed to maintain one of two speeds, either 30 mph, or 50 mph on the first half of the route, and the other speed on the second half. One trial was carried out under each of the three helmet conditions. The order of helmet conditions was rotated, so that across all riders, each half of the route was traveled an equal number of times at each speed for each helmet condition.

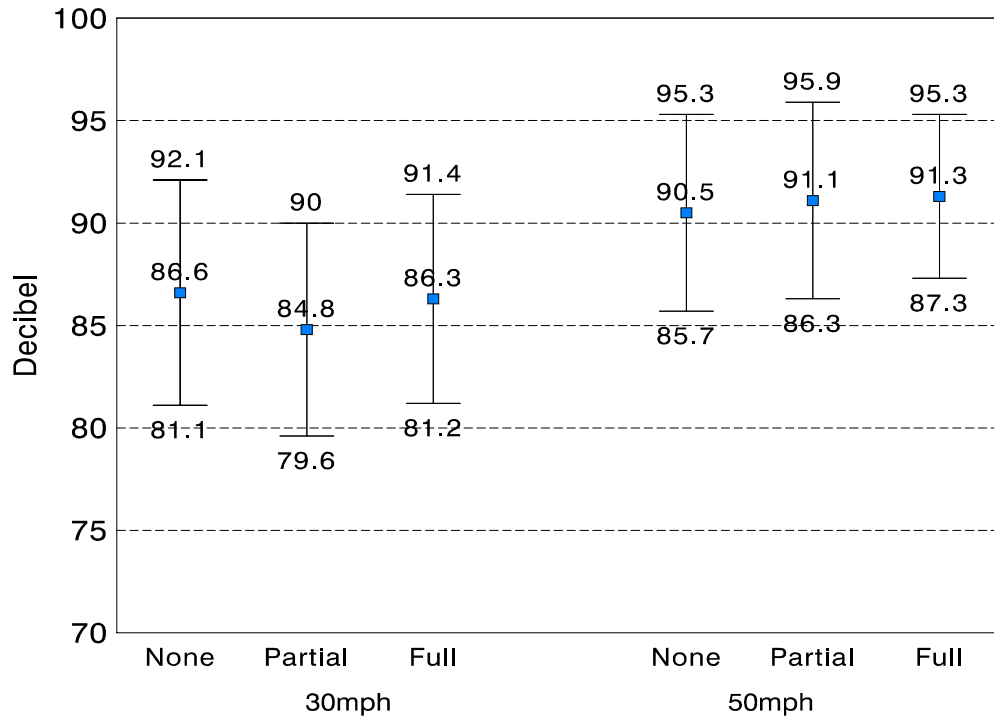
RESULTS

Results of Hearing Study

The sample of 24 riders yielded a total of 954 responses to sound signals, for an average of 6.6 responses for each rider under each combination of helmet condition and speed. As a result of traffic conditions, opportunities for lane changes varied between six and seven within each combination of helmet and speed, averaging 6.4 lane changes per rider.

The effect of helmets upon hearing is shown by the differences in the mean decibel level at which the sound signals were first detected under each of the three helmet conditions. The results are shown in Figure 1.

Figure 1 {PRIVATE}
 Mean (\bar{x}) Sound Threshold in Decibels
 by Speed and Helmet Condition



Tests of statistical significance appear in Table 2. The three-way interaction of Helmet, Speed, and Rider was highly significant ($F_{46,811}=2.92, p<.001$), meaning that the decibel level at which sounds were first detected varied for different combinations of the three variables. The three way interaction therefore served as the error term against which the effects of helmet type were tested for significance.

Table 2
Analysis of Variance
Tests of Significance for Hearing Threshold Using Unique Sums of Squares

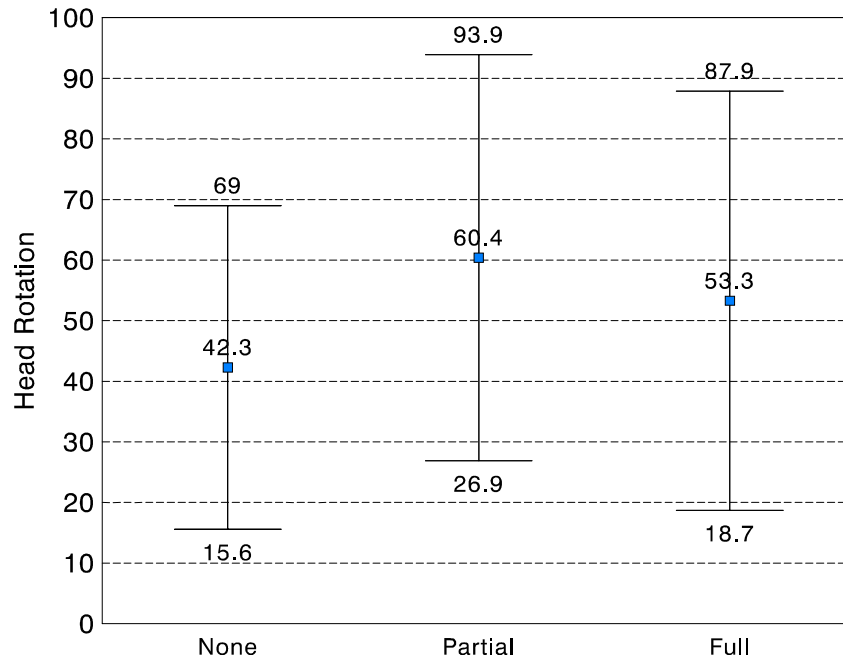
Source	Sum of Squares	Degrees of Freedom	Mean Square	Error Term	F	P
Helmet (H)	160.7	2	80.33	HxSxR	2.04	.142
Speed (S)	308.5	1	308.52	HxSxR	7.84	.007
Riders (R)	5561.2	23	241.79	HxSxR	6.14	<.001
Helmet by Speed	12.7	2	6.36	HxSxR	.16	.851
Helmet by Rider	1769.1	46	38.46	HxSxR	.98	.531
Speed by Rider	1157.3	23	50.32	HxSxR	1.28	.235
Helmet by Speed by Subject	1810.7	46	39.36	W	2.92	<.001
Within (W)	10925.7	811	13.47	---	---	---

The differences in ability to hear for the different degrees of helmet coverage, including with and without a helmet, turned out to be very small; an analysis of variance showed them falling well short of statistical significance ($F_{2,46}=2.04$, $p=.14$). Significant differences in the ability of individual riders to hear occurred across all helmet and speed conditions ($F_{23,931}=14.91$, $p<.001$), with differences among riders accounting for 27% of all the differences found. However, the actual magnitude of differences among riders was relatively small in magnitude, varying only about 5 db across all riders. The lack of greater differences among riders is somewhat surprising in view of the large variation in motorcycles in characteristics likely to affect detection of signals, such as differences engine noise and presence or absence of a fairing. That the sound measures were truly sensitive to the ability to hear is was evident in the significant difference between the two operating speeds, 30 mph and 50 mph ($F_{1,23}=6.132$, $p=.021$) with more difficulty in detecting sound at faster speeds.

Results of Vision Study

The 23 riders furnishing complete data yielded a total of 948 responses to the lane change signal, an average of 6.92 responses per rider for each individual combination of helmet condition and speed. The degree of head rotation for each level of helmet induced visual restriction is shown in Figure 2.

Figure 2
 Mean (\bar{v}) Degree of Head Rotation by Helmet Condition



Analysis of variance in degree of head rotation appears in Table 3.

Table 3
 Analysis of Variance
 Tests of Significance for Degree of Head
 Rotation Using Unique Sums of Squares

Source	Sum of Squares	Degrees of Freedom	Mean Square	Error Term	F	P
Helmet (H)	41632.20	2	20816.10	HxR	22.53	<.001
Rider (S)	660713.53	22	30032.43	HxR	32.50	<.001
Helmet by Rider	40656.01	44	924.00	W	3.83	<.001
Within (W)	211942.99	879	241.12		—	—

A significant Helmet-by Rider interaction ($F_{44,879}=3.83, p<.001$) indicates that the degree of head rotation varied across combinations of helmet and rider. However, the differences among helmet conditions emerged as highly significant over and above the interaction ($F_{2,44}=22.53, p<.001$). In Figure 2, one can see a clear relationship between the mean degree of head rotation and the vision restriction imposed by the helmet. The *partial* coverage helmet,

with a 25E restriction in visual angle, yielded (60.4 - 42.3 =) 18.1E more mean head rotation than to the no-helmet condition. The *full* coverage helmet, with a 18E vision restriction yielded (53.3 - 42.3 =) 11E more head rotation than the no-helmet condition. With both helmets, the degree of head rotation fell short of fully compensating for the vision restriction.

Underlying the overall differences between helmet conditions were marked individual differences among riders. These differences were highly significant, as evidenced by a significant interaction between degree of visual restriction and rider, where the within-rider differences were used as a measure of error ($F_{22,44}=32.50$, $p<.001$). However, the differences largely involved amount rather than presence of compensating head turn. For 19 of the 23 riders, wearing helmets resulted in greater head rotation than riding without a helmet. Among the remaining four riders, the helmeted conditions produced neither more nor less more head rotation than the unhelmeted condition.

Riders differed widely in their characteristic degree of head rotation under any helmet condition, with standard deviations ranging from $\pm 26.7E$ for the *no-helmet* condition to $\pm 34.6E$ for the *full* condition. Differences among riders accounted for 70% of all the variation in head turn, while helmet vision restrictions accounted for only 4.4%, a difference of 16 to 1. In short, the differences in head turn due to the presence or absence of a helmet paled in comparison to the search habits of riders.

It is noteworthy that the correlation between the extent of head rotation and the time to complete the visual check was small and non-significant ($r=.2$, $p>.05$). Differences in time-to-complete across the three helmet conditions were not significant ($F=.04$, $p=.96$), meaning that the additional head rotation required by the full and partial coverage helmets did not increase the period of time during which the rider's gaze was diverted from the path ahead.

DISCUSSION

The results indicate that wearing helmets does not restrict the ability to hear horn signals nor does it have an appreciable effect upon the likelihood of visually detecting a vehicle in an adjacent lane prior to initiating a lane change. In the case of hearing, neither the type of helmet, or its use at all, influenced the minimum detectable sound level. That the experimental procedure was capable of detecting true effects upon ability to hear, had they existed, is evidenced by the significant increase in required sound levels with increased vehicle speed. Yet, while helmets do not seem to degrade hearing, neither do they enhance it.

With respect to vision, the sight limitations imposed by helmets were largely compensated for by increased head turn. The small remaining differences in head turning were dwarfed by prevailing differences among the individual riders. Moreover, the slight increase in head rotation required for visual detection did not result in any increase in the time that gaze was diverted from straight ahead. The type of crash most likely to result from failure to see other vehicles is one in which a vehicle occupies a lane that a rider attempts to enter. An indication of the proportion of motorcycle crashes involving lane changing or merging can be found in the Fatality Analysis Reporting

System (FARS) Data Files (1999). For fatal crashes involving motorcycles, such maneuvers account for only 2.5% of crashes. Even if the small differences in head turn were to yield a proportional increase in crash risk, the proportion of total crashes affected by increased risk would be extremely low, far lower than the reduction in serious injury and death resulting from helmet use.

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REFERENCES

Aldman, B., Gustaffson, H., Nygren, A. & Wersall, J. Hearing and motorcycle helmets. *Journal of Traffic Medicine*, 11:42-44; 1983.

Evans, L. & Frick, M. Helmet effectiveness in preventing motorcycle driver and passenger fatalities. *Accident Analysis and Prevention*, Vol. 20, No. 6:447-458; 1988.

Gordon, S. & Prince, J. *Field of view with and without motorcycle helmets*. (Technical Report) National Highway Traffic Safety Administration: Washington, DC. (DOT HS-801-75); 1975.

Harrison, R. *The effectiveness of motorcycle helmets as hearing protectors*. (Project Record ED&T 2210). USDA Forest Service; 1973.

Henderson, R.L. *Effect of safety helmets on auditory capability*. Washington, DC: National Highway Traffic Safety Administration. (Technical Note No. DOT-HS-801-759); 1975.

Hurt, H. Jr. *Status report of accident investigation data motorcycle accident cause factors and identification of countermeasures*. Traffic Safety Center, University of Southern California: Los Angeles, CA. (DOT-HS-501160); 1979.

McKnight, A.J., McPherson, K. & Knipper, A.C. *Motorcycle rider advancement course plan*. National Highway Traffic Safety Administration: Washington, DC. (DOT-HS-7-01735); 1980.

National Highway Traffic Safety Administration & the Center for Statistics and Analysis, *Fatality Analysis Reporting System Data Files*, Washington, DC. 1999.

Purswell, J.L. & Dorris, A.L. Auditory and biomechanical performance requirements for motorcycle helmets. *Proceedings of the Human Factors Society - 21st Annual Meeting*. 1977; 226-230.

Saunders, A. Helmet vision: Seeing is believing. *Motorcyclist*, pp. 31-42; 1991.

Satsangi, K.; Howell, A.R. Wind noise exposure of motorcycle riders. *American Society of Mechanical Engineers Papers*, 9, pp. 5.; 1979.

Tetard, C. & Gauze, A. *Ergonomic study of helmets for moped riders*. France Avenue du General Mallaret-Joinville, BP 28 94114 Arcueil Cedex, France : National Road Safety Organization; 1978.

VanMoorhem, W.K., Shepherd, K.P., Magleby, T.D. & Torian, G.E. *The effect of motorcycle helmets on hearing and the detection of warning signals*. Salt Lake City, Utah: Department of Mechanical and Industrial Engineering, University of Utah; 1977.

Wilson, D.C. *The effectiveness of motorcycle helmets in preventing fatalities : NHTSA Technical Report*. Washington, DC: National Highway Traffic Safety Administration. (DOT HS 807 416); 1989.