

Noise exposure in convertible automobiles

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Abstract

Objective: To quantify the noise exposure received while driving a convertible automobile with the top open, compared with the top closed.

Methods: Five different convertible automobiles were driven, with the top both closed and open, and noise levels measured. The cars were tested at speeds of 88.5, 104.6 and 120.7 km/h.

Results: When driving with the convertible top open, the mean noise exposure ranged from 85.3 dB at 88.5 km/h to 89.9 dB at 120.7 km/h. At the tested speeds, noise exposure increased by an average of 12.4–14.6 dB after opening the convertible top.

Conclusion: Driving convertible automobiles at speeds exceeding 88.5 km/h, with the top open, may result in noise exposure levels exceeding recommended limits, especially when driving with the convertible top open for prolonged periods.

Key words: Hearing Loss; Noise-Induced; Automobile; Noise

Introduction

Noise exposure is one of the most important causes of hearing loss in modern society, and has a significant impact on quality of life and on the economy.^{1,2} Once incurred, sensory hearing loss is often irreversible; however, it is preventable. Much research has been done to help minimise noise-induced hearing loss in the workplace, and to identify sources of recreational noise exposure, in order to enable appropriate counselling of individuals with potential exposure.

While exposure to intense noise in excess of 140 dB may cause physical damage to the stereocilia, hearing loss caused by noise in the 85–140 dB range is thought to result from metabolic rather than mechanical changes in the cochlea. Over-stimulation leads to an accumulation of reactive oxygen species, with resulting cell damage and cell death. Continued exposure may result in the loss of inner hair cells and supporting cells, as well as secondary neural degeneration.^{3–5}

The extent of noise-induced hearing loss depends on several factors, including the intensity and duration of noise. Noise intensity is measured on a logarithmic scale and reported in decibels. As the intensity and length of noise exposure increase, the risk of noise-induced hearing loss increases. The US National Institute of Occupational Safety and Health and the US Occupational Safety and Health Administration have each established a time-weighted average

maximum acceptable exposure for workers in noisy environments. The standard set by the National Institute of Occupational Safety and Health is an 8-hour time-weighted average permissible exposure limit of 85 dB with a 3-dB trading ratio; that set by the Occupational Safety and Health Administration is an 8-hour time-weighted average permissible exposure limit of 90 dB with a 5-dB trading ratio (see Table I). The trading ratio means that the allowable exposure time is halved for each 3-dB increase in noise level, for the National Institute of Occupational Safety and Health guidelines, or for each 5-dB increase, for the Occupational Safety and Health Administration guidelines.^{6,7} Both organisations also recommend that preventative action be taken when workers are exposed to noise levels of 85 dB or more.

The present study used the National Institute of Occupational Safety and Health noise exposure levels, i.e. noise of 85 dB or more was considered excessive.

While US federal regulations are intended to protect workers from noise-induced hearing loss in the workplace, many recreational sources of noise exposure have been identified, including motorcycle riding,^{8,9} stock car racing,¹⁰ snowmobile riding,¹¹ rifle hunting¹² and hockey games.¹³

This study examined whether driving convertible automobiles should be added to the list of non-workplace

TABLE I RECOMMENDED PERMISSIBLE EXPOSURE TIME LIMIT BY NOISE INTENSITY: NIOSH & OSHA			
Exposure time	Noise intensity NIOSH (dB)	Noise intensity OSHA (dB)	Visual representation of relative noise exposure
8 hrs	85	90	■
4 hrs	88	95	□
2 hrs	91	100	○
1 hr	94	105	○
30 min	97	110	○
15 min	100	115	○

NIOSH = National Institute of Occupational Safety and Health;
OSHA = Occupational Safety and Health Administration

activities that warrant a recommendation for hearing protection.

Materials and methods

Serial sound level measurements were taken while driving various models of convertible automobile on the open highway. The models are 2009 Saturn Sky turbo made by Saturn Corporation, Detroit, Michigan, USA, 2004 Nissan 350Z made by Nissan Motor Company, Nishi-ku, Yokohama, Japan, 2001 Porsche 911 C4 made by Porsche Automobil Holding, Stuttgart, Baden-Württemberg, Germany, Saab Aero made by Saab Automobile, Trollhättan, Sweden, 2005 Ford Mustang made by Ford Motor Company, Dearborn, Michigan, USA; Measurements were taken by the passenger of the car, using a Quest Technologies model 210 sound level meter (Quest, Oconomowoc, Wisconsin, USA). Each data point represented the maximum reading over three seconds of noise surveillance. Sets of eight to 10 measurements were taken from the driver's left ear position. This process was repeated for each car, both with the convertible top closed and open. The term 'top open' indicated that the passenger compartment was fully open to the environment, including fully opened windows, while 'top closed' indicated a closed vehicle compartment, with the roof closed above the driver and all

windows closed. Measurements were taken at the following speeds: 88.5 km/hour (55 miles per hour (mph)), 104.6 km/h (65 mph) and 120.7 km/h (75 mph).

During all data collection, the car radio was turned off, there was no conversation between the occupants, the forced air mechanism was turned off, the car horn was not used, and there was no rain or other inclement weather.

Data analysis was performed using the Microsoft Excel 2007 software program.

Results and analysis

Data points were collected and averaged for each automobile. The results for all cars are summarised in Table II. Tables III to VII show the results for each individual car.

The results for the 2009 Saturn Sky 2.0 Turbo are summarised in Table III. This car had the loudest mean noise values of any car tested, at any given speed, producing 98.7 dB when driven at 120.7 km/h with the top open.

Table IV shows the results for the 2004 Nissan 350 Z. This car produced the overall maximum dB reading: 104 dB when driven at 120.7 km/h with the top open.

The 2001 Porsche 911 C4 results are summarised in Table V. This was the noisiest car with the top closed, producing 77.8 dB when driven at 120.7 km/h.

Table VI shows the results for the 2005 Saab Aero Convertible. This was the quietest car, with a mean noise level of 71.2 dB when driven both at 88.5 km/h and at 104.6 km/h.

The 2005 Ford Mustang GT Convertible results are summarised in Table VII. This was a relatively quiet car, with a loudest mean noise exposure of 84.7 dB and a maximum value of 88.6 dB both at highest speed tested of 120.7 km/h.

For all cars studied, the mean noise exposure was found to be higher with the top open than with the top closed. Table VIII shows the magnitude of noise exposure increase, comparing measurements taken with the convertible top closed versus open.

Discussion

In this study, excessive noise exposure was defined as 85 dB or greater, in accordance with the National Institute of Occupational Safety and Health limit for permissible exposure.

TABLE II
NOISE EXPOSURE FOR TESTED CARS

Car model	NE, top open (mean (max); dB)			NE, top closed (mean (max); dB)		
	88.5 km/h	104.6 km/h	120.7 km/h	88.5 km/h	104.6 km/h	120.7 km/h
2009 Saturn Sky 2.0 Turbo	91.1 (101.6)	95.9 (103.7)	98.7 (103.5)	73.5 (77.7)	72.9 (74.3)	75.2 (77.9)
2004 Nissan 350 Z	88.0 (97.9)	91.3 (101.2)	95.3 (104)	73.0 (76.8)	73.4 (75.8)	75.7 (80.0)
2001 Porsche 911 C4	81.1 (84.8)	86.9 (95.9)	86.0 (91.7)	74.6 (80.7)	76.4 (81.7)	77.8 (79.5)
2005 Saab Aero Convertible	84.2 (90.3)	84.3 (90.0)	84.6 (87.3)	71.2 (76.1)	71.2 (75.0)	73.5 (80.7)
2005 Ford Mustang GT Convertible	82.4 (87.0)	83.5 (86.7)	84.7 (88.6)	72.5 (74.0)	74.9 (75.9)	76.7 (79.3)

Mean noise exposure (NE) levels were calculated from several readings. Max = maximum

TABLE III
NOISE EXPOSURE FOR 2009 SATURN SKY 2.0 TURBO

Speed (km/h)	NE, top closed (dB)			NE, top open (dB)		
	Mean	Max	SD	Mean	Max	SD
88.5	73.5	77.7	1.6	91.1	101.6	7.5
104.6	72.9	74.3	1.1	95.9	103.7	3.0
120.7	75.2	77.9	1.3	98.7	103.5	4.1

NE = noise exposure; max = maximum; SD = standard deviation

TABLE IV
NOISE EXPOSURE FOR 2004 NISSAN 350 Z

Speed (km/h)	NE, top closed (dB)			NE, top open (dB)		
	Mean	Max	SD	Mean	Max	SD
88.5	73.0	76.8	1.5	88.0	97.9	4.5
104.6	73.4	75.8	1.5	91.3	101.2	5.0
120.7	75.7	80.0	2.1	95.3	104.0	6.2

NE = noise exposure; max = maximum; SD = standard deviation

TABLE V
NOISE EXPOSURE FOR 2001 PORSCHE 911 C4

Speed (km/h)	NE, top closed (dB)			NE, top open (dB)		
	Mean	Max	SD	Mean	Max	SD
88.5	74.6	80.7	1.8	81.1	84.8	1.8
104.6	76.4	81.7	2.0	86.9	95.9	4.0
120.7	77.8	79.5	1.2	86.0	91.7	2.6

NE = noise exposure; max = maximum; SD = standard deviation

TABLE VI
NOISE EXPOSURE FOR 2005 SAAB AERO CONVERTIBLE

Speed (km/h)	NE, top closed (dB)			NE, top open (dB)		
	Mean	Max	SD	Mean	Max	SD
88.5	71.2	76.1	2.2	84.2	90.3	2.5
104.6	71.2	75.0	1.3	84.3	90.0	3.0
120.7	73.5	80.7	2.2	84.6	87.3	1.7

NE = noise exposure; max = maximum; SD = standard deviation

TABLE VII
NOISE EXPOSURE FOR 2005 FORD MUSTANG GT CONVERTIBLE

Speed (km/h)	NE, top closed (dB)			NE, top open (dB)		
	Mean	Max	SD	Mean	Max	SD
88.5	72.5	74.0	0.8	82.4	87.0	2.7
104.6	74.9	75.9	0.8	83.5	86.7	2.2
120.7	76.7	79.3	1.2	84.7	88.6	2.2

NE = noise exposure; max = maximum; SD = standard deviation

TABLE VIII
AVERAGE NOISE EXPOSURE DIFFERENCE FOR TOP OPEN VS CLOSED

Car model	NE difference (dB)		
	88.5 km/h	104.6 km/h	120.7 km/h
2009 Saturn Sky 2.0 Turbo	17.6	23.0	23.5
2004 Nissan 350 Z	15.0	17.9	19.7
2001 Porsche 911 C4	6.6	10.5	8.1
2005 Saab Aero Convertible	13.0	13.1	11.1
2005 Ford Mustang GT Convertible	9.9	8.6	8.0
Overall	12.4*	14.6†	14.1‡

Standard deviations for overall results: *4.3, †5.8, ‡7.1. NE = noise exposure

At no time during the study were excessive noise levels recorded from any tested automobile driven with the top closed. Therefore, it is accepted that there is no more than minimal risk of excessive noise exposure when driving under the conditions tested with the convertible top closed.

When the convertible cars were driven with the top open, high levels of noise were consistently recorded. Excessive mean noise (i.e. greater than 85 dB) was recorded in 40 per cent of the cars at 88.5 km/h, and at that speed 80 per cent of the cars had maximum sound recordings greater than 85 dB. The only car in which excessive noise levels were not recorded, when driven at 88.5 km/h with the top open, was the 2001 Porsche 911 C4; this car's highest noise intensity was 84.8 dB and its mean noise exposure 81.1 dB. When driven at 104.6 km/h and 120.7 km/h with the top open, 60 per cent of the cars produced excessive mean noise exposure readings, with 100 per cent of the vehicles producing at least one reading that was excessive. In the 2009 Saturn Sky 2.0 Turbo, the mean noise level recorded at 75 mph with the top open was 98.7 dB; this corresponds to a National Institute of Occupational Safety and Health recommended permissible exposure time of approximately 20 minutes. The 2004 Nissan 350 Z produced one recording of 104 dB, driven at 75 mph with the top open, which correlates to a National Institute of Occupational Safety and Health permissible exposure time of approximately 6 minutes.

Overall, the mean noise exposure inflicted on the driver of a convertible car driven with the top open was 85.3 dB at 88.5 km/h, 88.4 dB at 104.6 km/h and 89.9 dB at 120.7 km/h. Figure 1 shows that, when the tested cars were driven with the top open, the National Institute of Occupational Safety and Health time-weighted average permissible noise exposure limit was surpassed at all speeds (i.e. 85.3 km/h and above). Not only was the mean noise exposure excessive with the top open, but the driver seemed to be exposed to extreme noise 'spikes' while driving on the highway (e.g. when driving next to a motorcycle or truck).

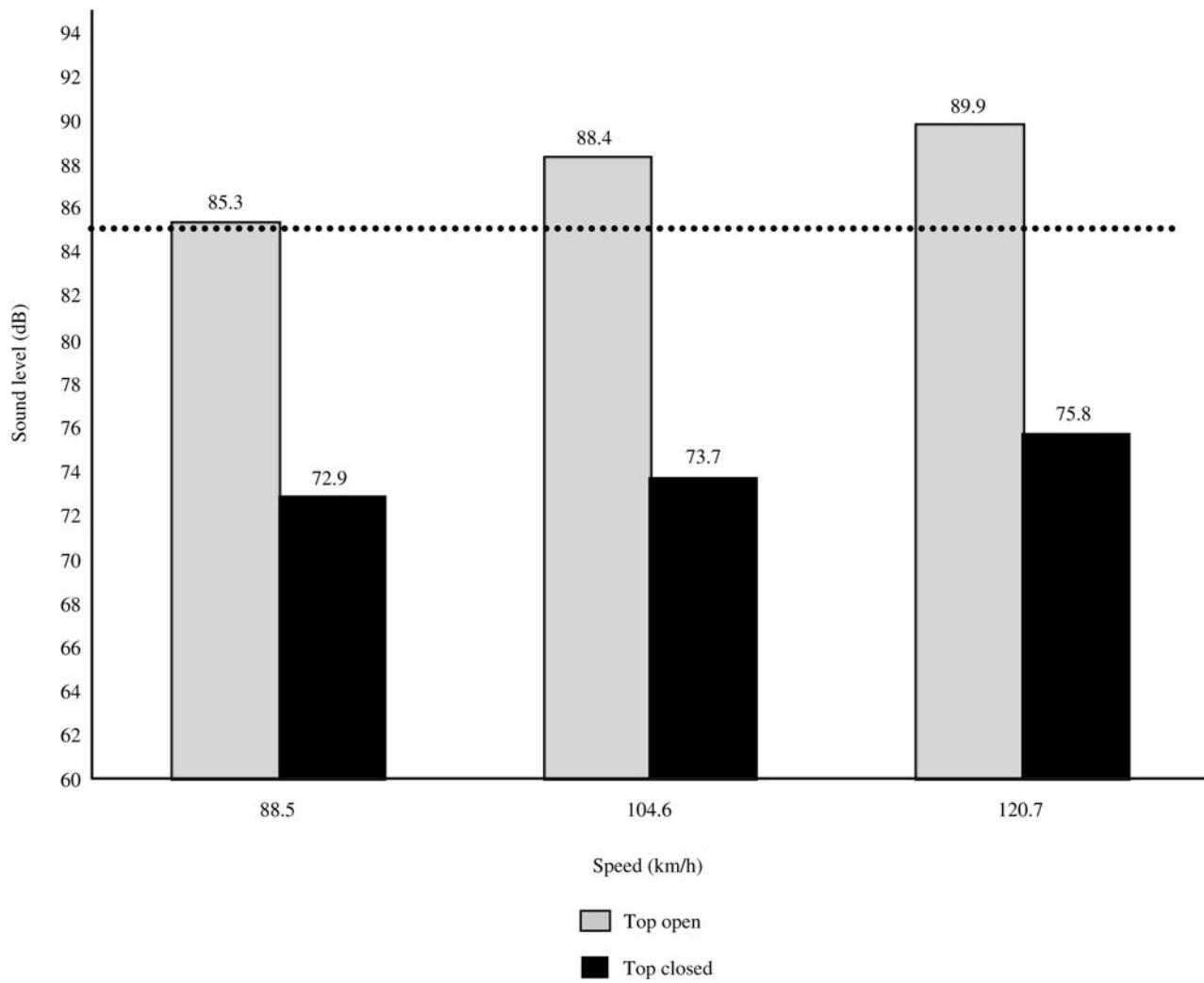


FIG. 1

Mean noise exposure in all cars at various speeds, with top open and closed. Dotted line indicates National Institute of Occupational Safety and Health permissible noise exposure limit.

Thus, drivers of convertible automobiles are potentially at increased risk of noise-induced hearing loss. We recommend that such drivers be advised to drive with the top closed when exceeding 85.3 km/h, or to use noise reduction devices such as earplugs or noise-cancelling headphones (taking into consideration the safety and legal concerns associated with these devices, if the driver is less aware of such roadway noise as car horns and emergency vehicle sirens).

Although driving for short distances under such levels of noise exposure is unlikely to cause a significant degree of noise-induced hearing loss, more frequent driving at high speeds with the convertible top open will increase the driver's risk of hearing damage.

Although not addressed in this study, drivers of convertible automobiles may be exposed to additional noise when listening to the car radio. Even for comfortable listening, the radio volume levels required while driving under the conditions assessed in this study are likely to add significantly to the noise exposure

level. Further research is needed to evaluate hearing damage in convertible automobile drivers, including the effect of car radio usage.

- **Motorised recreational activities (e.g. motorcycle and snowmobile riding and stock car racing) are known to be sources of excessive noise exposure**
- **This study assessed noise exposure while driving a convertible automobile**
- **The average noise exposure while driving such vehicles with the top open, at highway speeds, was 85.3–89.9 dB**
- **Drivers of convertible automobiles with the top open may experience noise levels of 104 dB or more at highway speeds**
- **Such noise exposure potentially places drivers at increased risk of noise-induced hearing loss**

Conclusion

Convertible automobiles can be a source of noise exposure that exceeds recommended levels, especially for prolonged journeys with the top open on busy motorways. Closing the top provides substantial protection from noise exposure.

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