Occupational noise exposure and noise-induced hearing loss are associated with work-related injuries leading to admission to hospital

Serge-André Girard,1 Tony Leroux,1,4 Marilene Courteau,1 Michel Picard,2 Fernand Turcotte,3 Olivier Richer1

ABSTRACT
Objective This study focuses on work-related injuries that required admission to hospital in a population of male workers exposed to occupational noise (≥80 dBA) which some displayed a hearing loss due to their exposure.

Methods The study population count 46 550 male workers, 1670 (3.6%) of whom incurred at least one work-related injury requiring admission to hospital within a period of 5 years following hearing tests conducted between 1987 and 2005. The noise exposure and hearing loss-related data were gathered during occupational noise-induced hearing loss (NIHL) screening. The hospital data were used to identify all members of the study population who were admitted, and the reason for admission. Finally, access to the death-related data made it possible to identify participants who died during the course of the study. Cox proportional hazards model taking into account the noise level exposure at the time of the hearing test established the risk of work-related injuries leading to admission to hospital.

Results For each dB of hearing loss, a statistically significant risk increase was observed (HR=1.01 dB 95% CI 1.006 to 1.01). An association (HR=2.36 95% CI 2.01 to 2.77) was also found between working in an occupational ambient noise ≥100 dBA and the risk of injury.

Conclusions From a safety perspective, this issue is highly relevant; especially when workers are exposed to intense ambient noise and NIHL.

INTRODUCTION
The number of workers exposed to occupational noise in relation to the number of occupational injuries is a legitimate public health issue. Despite conceptual plausibility, the contribution of occupational noise, and the pending noise-induced hearing loss (NIHL) to work safety, remains a major concern with the phenomenon being paid only limited attention in the current literature. The strategies used to study the problem vary, but most studies confirm an association.1–10 When adjusting for age, the risk varies notably with noise level exposure.1 8–10 Workers’ hearing status,4 5 8–10 and circumstances surrounding the event causing the injury.8 Depending on the study consulted and the comparison group retained, between 12% and 60% of injuries are said to be attributable to noise exposure levels, workers’ hearing or both.1 6–8 Morata et al11 using a qualitative study design, have shown that safety of workers with hearing loss, who are exposed to loud noise, is compromised.

Despite the increasing numbers of studies confirming this association (see ref. 12 for a review), we are far from a point where we can specify levels of exposure or degree of hearing loss that would set some minimal and, therefore, acceptable risk of injury from a public health perspective. This is due, in part, to the current poor specification of cause to effect variables as may be influenced by injury circumstances. In particular, occupational noise exposure is very often self-reported,7 8 10 11 or the thresholds used to differentiate noisy from non-noisy workplaces vary.1–3 Workers’ hearing losses are also mainly self-reported,1 4 5 and studies using hearing measurements may not be specific enough to determine the occupational origin of hearing loss,3 thus lessening the case of noise exposure, and NIHL being a risk factor for work-related injuries.

Noise limits the ability to discriminate sounds and to understand speech independently of the hearing status.12 Kumar et al13 have argued that, in the presence of noise, there is even a reduction in speech and information processing abilities even among persons without any measurable hearing loss. There is some evidence showing that noise, notably through the masking effect, has the same effect, if not worse, on hearing-impaired persons, are not less sensitive to the noise of their work environment than those with normal hearing, notably in relation to the masking effect. More, in the presence of NIHL, upward spread of masking (masking of high-pitch signals by a low-frequency masker) may further degrade perception in noise.16 Increased risk for the safety of hearing-impaired workers exposed to loud noise has specifically been documented by Morata et al11 Such an environment affords their ability to hear warning signals, to monitor equipment or environmental sounds, and to communicate. Negative effect of noise on performance could be verified at noise levels between 90 dBA and 95 dBA.17 18 According to Stansfeld, laboratory studies have shown that exposure to levels exceeding 100 dBA contributes to altering the strategy chosen to perform a task and can reduce the amount of attention given to the task.19 Such noise levels are associated with increased distraction, poor speech or signals perception, especially in the context of dual task and fatigue, factors that may also compromise safety.2 3 20 21 Based on laboratory studies, Kjellberg suggested that effects might appear at much lower levels of exposure, varying with task complexity, context and conditions in which a task is executed.22 23 The pervasive interaction of the above variables helps
understand why noise exposure per se and, NIHL as an additional burden, might be involved in the chain of events responsible for injuries.

OBJECTIVES
The purpose of this study is to acquire more solid evidence about the association between occupational noise exposure, NIHL and safety at work by testing the association between occupational noise exposure level, hearing loss and the risk of work-related injury leading to admission to hospital in a large cohort of mostly blue-collars exposed to high levels of noise at work.

METHODS
We conducted a large retrospective cohort study of workers with long exposure to high level of occupational noise with the potential consequence of permanent hearing loss in which the association of the total number of reported work-related injuries leading to admission to hospital occurring during a 5-year period could be studied in relation with the latest hearing screening test completed for every participant.

Data sources
Three administrative databases were used for this study. Data describing noise exposure, and workers’ hearing status, were derived from the audiometric database of the Institut national de santé publique du Québec (Québec National Institute of Public Health) (INSPQ). This organisation conducts individual hearing screening tests within the context of workplace-specific health programmes and compiles the results of these tests in a centralised database. The protocol surrounding the conduct of these tests is based on ISO-6199, a standard that warrants highly reproducible and valid hearing threshold measurements. Each test is completed with a thorough auditory questionnaire to document potential causal factors of hearing loss. For the purpose of this study, only the results of the most recent audiometric examination conducted between 1987 and 2005 were considered. The INSPQ database was also used to characterise the occupational noise exposure. Noise measurements are performed by public health authorities only for occupations where noise exposure is suspected to be equal to or above 80 dBA-8 h. The second source of data is the Base de données sur la Maintenance et Exploitation des Données pour l’Étude de la Clientèle Hospitalière (MED ECHO), a registry of patients admitted to hospitals, for at least 1 day. The third source is the Quebec Death Registry containing all information about mortality occurring in the study population. This registry was used to determine when to end the follow-up period of a deceased worker. Audiometric, hospitalisation and death data were matched by name, date of birth and Medicare registration number.

Population
The source population consisted of 84 697 noise-exposed male workers from various industrial sectors. All of them were exposed to noise in their workplace (L[Aeq] 8 h ≥80 dBA) for a large part, if not all of their professional life; this to strengthen the likelihood of experimental effects given that greater exposure should lead to greater incidence of the anticipated effect. Hearing of all these potential participants was tested between 1987 and 2005. Participation to this study is limited to only those workers with normal-for-age hearing (in reference to ISO-7029, 1999) and those with hearing loss characteristic of exposure to noise (in reference to ISO-1999). A total of 55 146 (65.1%) are qualified as ‘otologically normal’ meaning, that they had either normal-for-age hearing or high-frequency hearing loss in the absence of any sign or symptom of ear disease and obstructing wax in the ear canals, and who have no history of undue exposure to noise except for occupational noise exposure as illustrated in figure 1. The data relating to noise levels at workplace are complete for 46 550 (84.4%) of otologically normal workers (figure 1).

The study population is made of 46 550 noise-exposed male workers (L[Aeq] 8 h ≥80 dB). Among them, 1670 (3.6%) had at least one work-related injury requiring admission to hospital within a period of 5 years following their last hearing test. More than 80% were blue-collar workers employed in the following industrial sectors: metal products manufacturing (17.2%), food and beverage industry (9.5%), lumber industry (9.1%), forestry and sawmills (7.8%), manufacturing industries (7.3%) and mines and quarries (7.2%). Noise, high prevalence of NIHL and high safety risk rates are dominant characteristics of these industrial sectors.

Variables
The independent variables of interest considered in the current analyses for this study are related to occupational noise exposure and hearing status of the workers. The dependant variable is occupational injury leading to admission to hospital. Worker’s age and duration of exposure to occupational noise are used as adjustment variables.

Noise exposure
Noise levels in the workplaces were measured by public health industrial hygienists during the weeks preceding the audiometric testing sessions. They are specific to the work environment at the time of hearing test, so they cannot be used to estimate career exposure levels. Only workers for whom the noise level information is sufficiently specific to fit within one of the following noise exposure categories are retained as participants in this study (see figure 1). Noise levels are divided into three categories: complies with Quebec’s exposure regulation (80–89 dBA), 10 dB above the current regulation (90–99 dBA) to capture what has long been considered excessive exposures, and much higher (intense) (≥100 dBA) to isolate those critical levels.
with potential of reducing the amount of attention given to the task.19

Hearing status
Because of the hypothesis that NIHL and occupational noise exposure compromise occupational safety, and since all participants are exposed to occupational noise, it was deemed appropriate to retain workers displaying a wide variety of high-frequency hearing threshold levels.8 The high-frequency hearing status, namely mean bilateral hearing loss at frequencies (3, 4 and 6 kHz) is used as a continuous variable. Figure 1 summarises the population selection process and presents the hearing characteristics of workers excluded from the study.

Age and duration of noise exposure
The age of participants at the time of their last audiometric test (starting point of the follow-up), and the number of years of occupational noise exposure (1 year=2000 h), as reported by the workers, are factored in the various analyses. These two variables are handled as continuous variables.

Injury
During the follow-up period, 1670 work-related injuries leading to admission to hospital were identified from the MED_ECHO database, with each occurrence being the dependant variable. The ICD-9 classification has been used to describe the injury and the billing code recorded in the hospital admission registry to ascertain that the injury was work-related.

Strategies of analysis
Descriptive analyses were first carried out to summarise the data and to learn more about study population with respect to variables of interest. χ² Tests and Student t tests were used to verify whether the associations between admission to hospital for work-related injury and the independent variables (hearing status, occupational noise level and duration of occupational noise exposure) were of statistical significance.

In a second step, the Cox proportional hazards model was used to evaluate the risk of work-related injury leading to admission in relation to hearing status, noise level and duration of occupational noise exposure. This model was deemed appropriate for this type of analysis with follow-up duration varying from one worker to another depending on the exact time of occurrence of the event leading to the injury. Moreover, the key assumption of proportionality of hazards was met. Hearing status, occupational noise levels and duration of exposure at the time of hearing screening test are included in the model. The inclusion of an interaction variable between noise levels and hearing loss was also tested. The variable age is included in the model as an adjustment variable. For all participants, follow-up begins on the day of their last hearing test, and ends either after (1) 5 years, (2) a first work-related injury leading to admission, (3) the worker’s death or (4) 31 December 2005, the date the study ended (whichever came first). Duration of follow-up was based on the assumption of stable hearing thresholds (±10 dB) over a period not exceeding 5 years for the same level, or reduction of exposure to occupational noise.8

RESULTS
As shown in table 1, injured participants significantly differ from controls in terms of noise exposure levels (p<0.0001) and degree of hearing loss (p<0.0001).

As the Cox proportional hazards model presented in table 2 indicates, there is a statistically significant association between hearing loss and injuries. In fact, for each dB of hearing loss, a significant increase of the risk of injury occurs (HR=1.01dB 95% CI 1.006 to 1.013). Moreover, while there is a non-significant association of exposure to the 90–99 dBA noise level category (HR=1.069 95% CI 0.965 to 1.184), a significant association (HR=2.36 95% CI 2.01 to 2.77) is present between exposure to intense noise levels (≥100 dBA) and the risk of injury requiring admission to hospital. Therefore, exposure-related variables (noise levels and degree of hearing loss) are significantly associated with the risk of work-related injury leading to admission to hospital.

These results indicate, for example, that, in comparison to participants without hearing loss (0 dB HL), and assuming a work environment of 80–89 dBA, participants with a severe hearing loss (≥50 dB HL) and working in an environment where noise exposure is overly intense (≥100 dBA) have an increased risk of a work-related injury leading to admission to hospital (HR) which can be estimated at 3.56. Finally, as the interaction variable between noise levels and hearing loss is not significant (p>0.33), it was not included in the model.

DISCUSSION
This study bears on work-related injuries severe enough to lead the victims to be admitted to hospital. The results do not show that age and duration of noise exposure are directly involved in

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Table 1  Comparison of uninjured and injured workers of the study population according to age, duration of exposure, hearing loss and noise levels

<table>
<thead>
<tr>
<th>Variables</th>
<th>Uninjured workers</th>
<th>Injured workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Age</td>
<td>38.0</td>
<td>10.9</td>
</tr>
<tr>
<td>Duration of exposure</td>
<td>14.8</td>
<td>10.3</td>
</tr>
<tr>
<td>Hearing loss (dB)*</td>
<td>18.0</td>
<td>16.4</td>
</tr>
<tr>
<td>Noise level†</td>
<td>N Per cent</td>
<td>N Per cent</td>
</tr>
<tr>
<td>80–89 dBA</td>
<td>22 444</td>
<td>50.1</td>
</tr>
<tr>
<td>90–99 dBA</td>
<td>20 283</td>
<td>45.1</td>
</tr>
<tr>
<td>≥100 dBA</td>
<td>2153</td>
<td>4.8</td>
</tr>
<tr>
<td>Total</td>
<td>44 880</td>
<td>100.0</td>
</tr>
</tbody>
</table>

*Student t test—p value<0.0001.
†χ² Test—p value<0.0001.

Table 2  Cox proportional hazards model* describing the contribution of age, duration of exposure, noise levels and hearing loss to risk of injury leading to admission to hospital

<table>
<thead>
<tr>
<th>Variables</th>
<th>HR</th>
<th>95% CI</th>
<th>Pr&gt;χ²(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>0.99</td>
<td>0.98</td>
<td>1.001</td>
</tr>
<tr>
<td>Duration of exposure</td>
<td>1.005</td>
<td>0.99</td>
<td>1.01</td>
</tr>
<tr>
<td>Noise level†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80–89 dBA</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90–99 dBA</td>
<td>1.07</td>
<td>0.97</td>
<td>1.18</td>
</tr>
<tr>
<td>≥100 dBA</td>
<td>2.36</td>
<td>2.01</td>
<td>2.77</td>
</tr>
<tr>
<td>Hearing loss†</td>
<td>1.01†</td>
<td>1.006</td>
<td>1.013</td>
</tr>
</tbody>
</table>

*Follow-up time (maximum 5 years).
†Age, duration of exposure and hearing loss, handled as continuous variables.
†Risk for 1 dB of hearing loss.

the events studied. However, working in an environment where the noise levels are ≥100 dBA, or having NIHL, are significantly associated with the risk of injury.

These results indicating that NIHL (HRdB=1.01 95% CI 1.006 to 1.013) contributes significantly to the risk of injury supports previous studies results. For example, workers with severe high-frequency hearing loss (≥50 dB HL) would carry HR that we can overall estimate to 1.6 (95% CI 1.35 to 1.91). For noise levels, the burden of working in an environment characterised by noise levels ≥100 dBA translates into a HR of work-related injury leading to admission to hospital amounting to 2.36 (95% CI 2.01 to 2.77). The non-significant association between working at levels between 90 and 99 dBA and injury (HR=1.07 95% CI 0.97 to 1.18) may simply be the result of the current restriction to events that have led admission to hospital. A less stringent criterion would likely have produced a different outcome.

It is clear that assigning workers to environments equal to or above 100 dBA may prove equally detrimental to workers’ hearing than it would be to their safety. Furthermore, the results show that the simultaneous presence of excessive noise and NIHL is particularly risky.

The contribution of these results is substantial. Referring to hearing status, they are consistent with previous work documenting the extra burden when injuries are serious enough to require hospitalisation. They are also comparable to those reported by Palmer et al.,12 reporting a mean increase of the OR associated with hearing problems in the various studies they examined stands between 1.5 and 2.0. This represents a 50% to 100% so-called ‘moderate’ increase risk. Current observations are in agreement with Kjellberg finding that hearing-impaired persons are not less sensitive to occupational noise than normal hearers.14

The observation that a high-injury risk is associated with exposure levels (≥100 dBA) emphasises the particular detrimental nature of this type of exposure. A previous study has verified the association between such exposure level and incidents, but in the context of road safety. Thus, current findings add to the generality of theoretical framework of overly intense noise levels compromising safety.

In Quebec, it is estimated that up to 4300 workers in over 500 workplaces are exposed daily to intense noise levels (≥100 dBA). In the USA, data from the 1980s indicate that some 506 000 workers were exposed to same levels of magnitude (≥100 dBA). There are no recent global statistics, but according to these authors, workers of various industries in Hong Kong, India and Nigeria were exposed to such noise levels. Thus, it seems that this phenomenon is not specific to Quebec.

In reference more specifically to Toppila et al29 and El Dib et al,30 this issue remains a major concern. There is indeed no indication that awareness raising or prevention activities addressing the injury risk exist for workers who suffer from hearing loss, or are exposed to significant noise levels (≥90 dBA).

Strengths and limitations
A major strength of this study is that it focuses on the impact of occupational noise and NIHL on occupational safety. However, this study has limitations that should be mentioned. First, this study considers only injuries requiring admission to hospital, a fraction only of the total number of accidental events in noisy workplaces. One consequence is that the risk of injury is probably underestimated. However, these injuries were quite serious. This limitation possibly explains, at least partly, why neither age nor duration of noise exposure appeared to be significant in the analyses conducted. Age, as well as experience, traditionally has a protective effect in a safety perspective. Second, the available data precludes consideration of injury circumstances. Such consideration would make it possible to better understand the processes involved. Third, the fact that data on noise levels are not available for a large proportion of workers, reduces the number of workers and injuries that could be considered in the analysis. Fourth, absence of data related to job description of workers limits the number of factors that can be considered in the analysis. However, the matching procedures and the fact that almost all these workers are manual workers, limits the impact of this limitation. Finally, the industrial sectors have not been included in the analyses. The inclusion of industrial sector in the analysis, adding a variable with so many modalities (n = 16) would be equivalent to adding 15 different binary variables to the model. This would result in a much expanded model with few cases distributed among each industrial sector leading to very large CI. It must, nevertheless, be noted that the noise levels are ≥80 dBA in all workplaces.

CONCLUSION
The contribution of noise exposure and of the resulting hearing loss to work-related injuries requiring hospitalisation remains an important issue that deserves attention of occupational health and safety personnel. In particular, the fact that hearing-impaired workers face particular problems when working in hazardous noise environments—equal to or greater than 100 dBA in the present study, is of special concerns. Injury analysis and investigation procedures introduced in noisy environments should provide a more detailed picture of the circumstances surrounding events involving exposed persons and injury victims. No doubt the resulting analysis would lead to a better understanding of the importance of the processes involved. Other avenues in relation to hearing health and exposure to noise levels exceeding standards should also be considered in the near future. Based on current findings, a good starting point to reduce work-related injuries requiring admission to hospital would be to prohibit working in environments where LAeq 8 h equals to or exceeds 100 dB. In the process of moving people to quieter locations, the highest priority should be given to those workers accomplishing the most cognitively demanding tasks (including jobs requiring multitasking skills) starting with the hearing-impaired.

What is already known on this subject
- Occupational noise is a public health concern.
- Occupational noise and noise-induced hearing loss are considered to be contributors to work-related injuries.

What this study adds
- Workers exposed to intense occupational noise (≥100 dBA) are at high risk of work-related injuries.
- Simultaneous presence of noise-induced hearing loss and working in intense noise is very harmful for workers’ safety.
- There is a confirmation that hearing-impaired persons are not less sensitive to the noise of their work environment than those without hearing loss.
Contributors Each of the authors made a substantial contribution to the production of this study. Each one contributed to its design and to every step of the project, whether the development of specifications, choosing the data analysis strategy or interpreting the results. Review and interpretation of the results were made with collective responsibility and taking advantage of the complementary expertise of the authors. The version to be published was approved by all authors. In addition, having seen that issues related to the accuracy or integrity of the work are properly addressed and resolved, everyone accepts the responsibility associated with this publication.

Competing interests None.

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REFERENCES
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