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A review of the current state of knowledge on tinnitus in relation to noise exposure and hearing loss

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A review of the current state of knowledge on tinnitus in relation to noise exposure and hearing loss

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This report details the results of a search of the published peer-reviewed literature investigating the relationship between tinnitus (ringing or buzzing in the ears), noise exposure at work and noise-induced hearing loss. A total of 12 citation databases (earliest date 1951) were searched which identified 252 publications, of which 34 were found to be relevant to the review. A number of studies have reported the prevalence of tinnitus in populations exposed to noise at work to be between 87.5% and 5.9%. Factors such as the type of participant (eg health surveillance, compensation claimant), the characteristics of the noise exposure and the definition of tinnitus used may contribute to this variability. Furthermore, four studies have shown that the prevalence of tinnitus in workers exposed to noise at work is significantly greater than in workers not exposed to noise. The majority of the published papers support the idea that there is an association between tinnitus and noise-induced hearing loss. The prevalence of tinnitus in those with hearing loss appears to be greater, and the hearing thresholds in those with tinnitus are higher. There is also a suggestion from one 15-year longitudinal study that tinnitus may be an early indicator of risk of the development of noise-induced hearing loss.

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EXECUTIVE SUMMARY

This report details the results of a search of the published peer-reviewed literature investigating the relationship between tinnitus (ringing or buzzing in the ears), noise exposure at work and noise-induced hearing loss. A full review of these issues has not previously been published in the peer-reviewed literature. A total of 12 citation databases (earliest date 1951) were searched which identified 252 potentially relevant publications. Following an initial sift of the corresponding abstracts, 34 publications were identified as being written in the English language and relevant to the objectives of this review. These form the basis of this report.

Objectives

To review the peer-reviewed literature to address two main questions:

1. Is there a relationship between exposure to noise in work and tinnitus?

2. Is there a relationship between tinnitus and hearing loss in those exposed to noise at work?

Main Findings

1. A number of studies have reported the prevalence of tinnitus in populations exposed to noise at work (n=23). The prevalence values vary considerably (87.5% to 5.9%) and factors such as the type of participant (e.g. health surveillance, compensation claimant), the characteristics of the noise exposure and the definition of tinnitus used may contribute to this variability.

2. Four studies have shown that the prevalence of tinnitus in workers exposed to noise at work is significantly greater than in workers not exposed to noise. Eight studies have also presented evidence to suggest that this is related to the severity (in terms of exposure level and duration) of noise exposure.

3. The majority of the published papers support the idea that there is an association between tinnitus and noise-induced hearing loss. The prevalence of tinnitus in those with hearing loss appears to be greater (shown in 7 out of 9 papers), and the hearing thresholds in those with tinnitus are higher (shown in 8 out of 9 papers).

4. The majority of the literature (33/34) included in this review are from cross-sectional studies, which makes it difficult to establish whether there is a causal relationship between tinnitus and hearing loss. However, one paper based upon the results of a 15-year longitudinal study has suggested that tinnitus may be an early indicator of risk of the development of noise-induced hearing loss.

Recommendations

It may be useful to widen the literature search to include general noise exposure, rather than purely noise exposure at work. This may help to increase the evidence base, particularly in terms of comparing the prevalence of tinnitus in individuals with and without a history of noise exposure, and whether there is information clarifying any causal relationship between tinnitus and hearing loss.

1 INTRODUCTION

Tinnitus manifests itself as ringing, buzzing or other sounds in the ear, without an external sound source. It may be intermittent or continuous. Some victims of tinnitus appear to tolerate their symptoms with little difficulty. However, others suffer from a wide variety of difficulties and the effects upon quality of life can be quite significant as it can affect concentration, ability to sleep and psychological well-being.

The causes of tinnitus are many and varied and include diseases of the ear, exposure to ototoxic drugs, cardiovascular problems, metabolic disorders and neurological problems [1]. In addition, a paper, which included a small review of papers relating to the prevalence of tinnitus in populations exposed to industrial noise, suggested that noise exposure and noise induced hearing loss were the most common causes of tinnitus [2]. However, this was not a full review of all the literature and it did not review the evidence for a dose-response relationship between tinnitus and noise exposure, or all the literature investigating the relationship between hearing loss and tinnitus.

The relationships between tinnitus and exposure to noise at work, and noise-induced hearing loss are of interest. In particular, if tinnitus were caused by exposure to noise and occurred prior to noise-induced hearing loss, it may be that reporting of tinnitus may be an early marker of risk of developing noise-induced hearing loss. If this were found to be the case then asking about tinnitus as part of a health surveillance programme for noise exposure at work would be of value in helping to identify those at risk, and helping to persuade individuals to protect themselves against the risk.

The current review aimed to interrogate the scientific peer-reviewed literature for evidence related to the relationships between tinnitus, noise exposure and noise-induced hearing loss. The specific questions addressed by this review are:

1. Is there a relationship between exposure to noise in work and tinnitus?
    a. Is the prevalence of tinnitus in those exposed to noise in work greater than those who aren't exposed to noise in work?
    b. Is there a relationship between tinnitus and the severity of exposure to noise?
2. Is there a relationship between tinnitus and hearing loss in those exposed to noise at work?
    a. Is the prevalence of tinnitus in those with noise-induced hearing loss greater than that in those with normal hearing?
    b. Are the hearing thresholds measured using audiometry greater in those with tinnitus as compared to those who do not have tinnitus?
    c. Is there evidence of an increased risk of tinnitus in those with hearing loss, or an increased risk of hearing loss in those with tinnitus?
    d. What is the temporal relationship between tinnitus and hearing loss?

2 METHODS

The information services search team at the Health and Safety Executive conducted the literature search. The terms used for the search were:

Tinnitus

(Ear or ears) with (ring* or buzz*)

work*, employ*, occupation*

The following twelve databases were searched for relevant information:

CINAHL	From 1981
HSELINE	From 1974
OSHLINE	From 1998
CISDOC	From 1987
NIOSHTIC	From 1971
RILOSH	1975-2004
MEDLINE	From 1951
EMBASE	From 1974
Healsafe	From 1981
Web of Science	From 1990
Ergonomics	From 1981
OshUpdate	From 1980

The search was restricted to literature in peer-reviewed scientific publications written in the English language.

Each of the searches was exported in a text file format and then imported into a reference manager (Endnote® 9). The abstracts were then reviewed by the author to determine which references were relevant to the current review. Hard-copies of the publications that were deemed relevant were then obtained and reviewed by the author.

3 RESULTS

3.1 PAPERS REVIEWED

The initial literature search identified 252 references that contained the selected keywords (see Section 2). However, when the author reviewed the references it was found that as different databases use different reference notation and nomenclature, that there were a substantial number of duplicates in the reference manager file. In addition, the references were filtered according to whether they were relevant to address the questions of this review, they were written in the English language and they were published in peer-reviewed publications. Following this process, 60 of the original 252 references identified by the search were obtained, as they were thought to be potentially relevant to the subject of this review. On detailed examination of the full references, it was found that only 34 of these contained information relevant to the questions addressed in this review. Therefore, only these references form the basis of the following report.

Of the 34 papers in the following review, 33 were from cross-sectional studies and only one was from a 15-year longitudinal study. The populations involved in these studies were predominantly (31/34 papers) those who were currently exposed, or had been exposed to occupational noise. Three of the studies involved the use of general populations, with one focussing on those over 55 years of age. However, all of the general population studies reported, investigated the risk of occupational noise exposure.

3.2 QUESTION 1 – IS THERE A RELATIONSHIP BETWEEN EXPOSURE TO NOISE IN WORK AND TINNITUS?

In order to establish whether there is a relationship between exposure to noise in work and tinnitus, we aimed to review the literature to address the following questions:

1. Is the prevalence of tinnitus in those exposed to noise in work greater than those who aren't exposed to noise in work?

2. Is there a relationship between tinnitus and the severity of exposure to noise (i.e. dose-response)?

3.2.1 Is the prevalence of tinnitus in those exposed to noise in work greater than those who aren't exposed to noise in work?

Twenty-three papers were identified that reported information on the prevalence of tinnitus in populations exposed to noise at work (evidence table one). However, only four of these publications also contained information related to the prevalence of tinnitus in a non-exposed population [3-6]. The prevalence of tinnitus in the non-exposed groups in these studies varied between 2 and 14.4%, with the highest prevalence being found in a general population study [3]. In the same studies, the prevalence of tinnitus in those exposed to noise ranged between 12 and 70.4%. In all four studies the prevalence in the noise-exposed group was statistically significantly higher than in the non-exposed group.

Nineteen references reported the prevalence of tinnitus in populations exposed to noise at work, but did not contain prevalence information of those not exposed to noise. The prevalence

reported in these studies ranged between 87.5% and 5.9%. Two of the studies, which have reported a very high prevalence of tinnitus, were conducted in drop-forge workers [6, 7]. The noise exposure in this industry is of an impulsive nature, rather than a continuous nature, and this may suggest that impulsive noise leads to more tinnitus. Some of the other studies with the highest prevalence of tinnitus have involved the use of claimants for noise-induced hearing loss [8, 9] and one other has involved the use of individuals reported for noise-induced hearing loss to the Register of Occupational Diseases in Finland [10]. Conversely, there have been three very large studies published, which have reported a relatively low prevalence of tinnitus in workers exposed to noise [11-13]. These studies have involved the use of noise-exposed populations of 110,647, 30,000 and 47,388 with reported prevalence of tinnitus of 6.7%, 6.6% and 5.9% respectively.

Factors such as the definition of tinnitus used, especially whether transient effects after exposure to noise are included, and the prevalence of noise induced hearing loss may also have an effect upon the reported prevalence of tinnitus. Evidence table one shows that many studies did not state the definition used for tinnitus and in many cases it was difficult to ascertain the prevalence of noise induced hearing loss in the population studied.

Evidence table one: Prevalence of tinnitus in populations exposed to noise at work (in order of prevalence of tinnitus reported in noise exposed population)

First Author	Year	Type of subjects	Noise exposure	Case definition for tinnitus	Age	Prevalence of noise-induced hearing loss	Prevalence of Tinnitus
Kamal, AA [7]	1989	88 drop-forge workers	Exposed to impact noise ranging between 112 to 139 dB(A) at a rate between 20-50 drops per minute	Not given	Between 30-60 years of age	91% (reported difficulty hearing the human voice)	87.5%
Bray, A [14]	2004	23 disc jockeys	Sound levels up to 108 dB(A) were recorded in nightclubs, with an average of 96 dB(A). No information on length of exposure.	Not given	Mean 29 (range 21-41) years	13%	74%
Sulkowski, W [6]	1999	261 drop forge operators	Peak pressure level for impulse noise of 135.1 dB.	Not given	Mean age 31.2 years.	Not given	70.4% in noise exposed. 3.5% in age-matched controls (chi-squared 185, $p<0.0001$)
Mrena, R [10]	2007	Cases of noise-induced hearing loss reported in the	Mean duration of exposure of 24.8 (range 0-50) years	Tinnitus mentioned (on basis of a full tinnitus questionnaire)	Mean age 51.6 years	40% (>20dB hearing thresholds).	67.7%

First Author	Year	Type of subjects	Noise exposure	Case definition for tinnitus	Age	Prevalence of noise-induced hearing loss	Prevalence of Tinnitus
		Register of Occupational Diseases in Finland in 2000. 366 individuals with disability category and contact information.				60% with mild NIHL (<20 dB).	
Barrs, DM [9]	1994	246 patients seeking compensation for noise-induced hearing loss	Mean duration of noise exposure was 28.1 years.	Not given	Mean age 56.4 (SD 8.2) years	Not given	58%
Alberti, PW [8]	1987	2,442 workers claiming compensation for hearing impairment in Toronto, Canada.	Mean exposure to intense workplace noise was 25.3 years.	Not given	Mean age of 56 years.	100%	58%

First Author	Year	Type of subjects	Noise exposure	Case definition for tinnitus	Age	Prevalence of noise-induced hearing loss	Prevalence of Tinnitus
Prasher, D [15]	2001	198 mill workers exposed to noise levels	85-95 dB(A) for a mean of 12 years.	Not given	Mean (SD) for those with tinnitus 47 (9) years and 39 (9) years for those without tinnitus.	Not given	52.5%
Jansen EJM [16]	2009	241 professional musicians	Not reported	Not given	23-64 years	Not reported	51%
McShane, DP [17]	1988	3,466 claimants for noise induced hearing loss	Mean exposure to workplace noise was 26.1 (SD 11.8) years	Includes both intermittent and continuous symptoms. Does not exclude symptoms following loud noise.	Average age 60.5 (range 16-81) years	99% (had hearing threshold >20dB)	49.8%
Kahari, K [18]	2003	139 rock/jazz musicians	Mean 19 (range 5-40) years as musician.	Not given	Median age in women 35 (26-47) years and 37 (26-51) years in men	49%	48%
Ylikoski, ME [19]	1994	786 Finnish army officers exposed to gunfire noise	Not reported	Defined as either occasional or continuous	Mean 39.8 (range 25-61) years	68% (>20 dB)	42.5%

First Author	Year	Type of subjects	Noise exposure	Case definition for tinnitus	Age	Prevalence of noise-induced hearing loss	Prevalence of Tinnitus
Lindgren, T[20]	2009	418 male and 42 female pilots	Not reported	Experienced tinnitus for more than 5 min during past year, reported constant or severe tinnitus	Mean age (SD) 46 (6.7) years	36%	40%
Hong, O [21]	2006	623 construction workers	Mean (SD) years in construction 18.14 (10.93) years.	Not given	Mean age (SD) was 42.96 (9.98) years.	60% (>25dB at 4, 6 kHz)	38%
Hong, OS [5]	1998	255 noise exposed and 195 non-noise exposed full-time airport workers	>85 dB(A)	Not given	Mean 38.9 years in noise exposed and 37.4 years in non-exposed	In noise group: 9.4% NIHL at low frequencies and 49.4% at high frequency. In non-noise group: 0.5% and 6.7% respectively.	32.2% in noise exposed 6.7% in controls (Chi-squared 41.6, $p<0.0001$)
Griest, SE [22]	1998	91 male employees exposed to noise	85-101 dB(A)	Not given	Range 18-41 years.	52% (hearing threshold ≥ 15 dB at 4kHz)	29.7%
Begault, D [23]	1998	64 commercial airline pilots	Not reported	Question: Do you have a buzzing, ringing or whistling in one or both ears (tinnitus)?	Median age 53 (range 35-64) years	Between 27 and 53% (depending on age)	29.5%

First Author	Year	Type of subjects	Noise exposure	Case definition for tinnitus	Age	Prevalence of noise-induced hearing loss	Prevalence of Tinnitus
Chen, J-D [24]	2003	384 noise-exposed workers in an oil refinery	Exposed to average noise level of 73-89 dB(A). Mean duration of exposure was 14 (SD 7) years	Question: Do you ever hear ringing in your ears?	Mean (SD) age 39 (5) years	38% (high frequency loss)	28%
Phoon, W [25]	1993	647 noise-exposed workers notified as cases of noise-induced deafness	Mean (SD) duration of exposure was 170 (100.7) months in those with tinnitus and 160 (106) months in those without tinnitus	Experienced any tinnitus within the past 6 months	Mean age 39 years	34% (hearing threshold >25 dB)	23.3%

First Author	Year	Type of subjects	Noise exposure	Case definition for tinnitus	Age	Prevalence of noise-induced hearing loss	Prevalence of Tinnitus
Coles, RRA [3]	1981	6,804 individuals from the general population in four cities of the UK	32.3% reported noise exposure	Question: Do you get ringing or buzzing noises in your head or ears. The occasional whistling or ringing in the ears of less than 5 minutes duration should not be counted. Also do not count those times when this happens after very loud sounds, e.g. discos, shooting or noise at work.	38% <40 years 32.8% 40-60 years 29.2% >60 years	Not given	In those aged 40-60, the prevalence of tinnitus in those not exposed to noise was 13.2% compared to 21.4% in those exposed. In those over 60 the respective proportions were 18.2 and 32.8%. Overall, the prevalence of tinnitus in those exposed to noise was 24% compared to 14.4% in those not exposed to noise (Chi-squared 69.7, p<0.0001).

First Author	Year	Type of subjects	Noise exposure	Case definition for tinnitus	Age	Prevalence of noise-induced hearing loss	Prevalence of Tinnitus
Chavalitsakulchai, P [4]	1989	1,531 workers in a textile mill. 613 weavers, 105 office workers and 813 doing other activities.	Average noise levels in the weaving section and other sections were 102.3 and 89.8 dB(A) respectively	Not given	Mean (SD) of weavers was 29 (6) years, office workers 32 (8) years and others 28 (5) years.	Not given	12% in noise exposed 2% in controls (Chi-squared 8.5, p=0.0035).
Neuberger, M [13]	1992	110,647 noise exposed workers	>85 dB for at least 6 months.	Not given	Aged between 15-65 years.	Median approximately 10% (Roeser's speech impairment index, those with no injury or disease)	6.7%
Chung, DY [12]	1984	30,000 noise exposed workers	Mean of 85 dB(A) or more	Question: Do you have ringing in your ears? (excluding transient tinnitus)	Not reported	Not given	6.6%
Bauer, P [11]	1991	47,388 noise-exposed workers	Median level 89.8 dB(A)	Not given	Median age 36.1 years	Not given	5.9%

3.2.2 Is there a relationship between tinnitus and the severity of exposure to noise?

A total of 9 papers were identified which investigated the relationship between severity of noise exposure and tinnitus (Evidence table two). Four of these publications used actual noise levels (dB(A)) as the noise exposure metric [26-29]. Of these four studies, one of them demonstrated a slight increase in prevalence of tinnitus with increasing noise levels in workers in the cement industry, but these differences were not statistically significant [29]. Another study showed that there was a weak relationship between the L_{Aeq} and tinnitus, which was statistically significant[26]. A further small study conducted in bar tenders and waitresses showed that individuals working in the louder clubs experienced more frequent bouts of tinnitus [27]. These three studies did not investigate whether the occurrence of noise-induced hearing loss was also an important factor. One final study which investigated the relationship between tinnitus and actual noise levels found that the cumulative noise exposure (dB(A)-years) significantly increased the risk of tinnitus ($p=0.03$), but only in those who had hearing loss [28].

Other studies have attempted to assess the severity of noise exposure by using self-reported questionnaires. In two of the studies, asking how difficult it was to speak or be heard in the work environment was used to establish the severity or level of noise exposure [30, 31]. A study by Sindhusake has shown that the relative risk of having tinnitus was related to the severity of work-related noise exposure. In those individuals whose exposure was tolerable the relative risk was 1.39 and in those where they were unable to hear speech, it was 1.53 [31]. This study involved the production of a predictive model for tinnitus and took into account confounding factors such as age, gender and hearing loss. However, one limitation of this study was that it was conducted in an older population with an average age of 69.8 years, therefore the relevance of these findings to the working population is unknown. Another study involving the general population has shown that the number of years working in a noisy job (defined as one where you need to shout to be heard) was related to the prevalence ratio for tinnitus [30]. In those individuals who had worked in a noisy job for 1-5 years the prevalence ratio was 1.8 and this increased to 2.6 in those who had worked in such an environment for more than 10 years. This study went on to suggest that 266,300 men have tinnitus in the UK as a consequence of work-related noise exposure.

Three studies have investigated the relationship between tinnitus and duration of noise exposure [6, 17, 32]. One of these studies demonstrated that the risk of tinnitus in musicians was related to the number of hours of practice per week [32]. Another study showed that the prevalence of tinnitus increased with the number of years of exposure in a drop-forge. However, whether these changes were statistically significant is difficult to ascertain as there was no statistical analysis included in this publication [6]. One further study involving the use of claimants for noise-induced hearing loss showed that the prevalence of tinnitus in those exposed for 0-10 years was 33.7% and that this rose to 54% in those exposed between 11-20 years. However, with durations of exposure greater than 20 years, the prevalence remained fairly stable [17].

Evidence table two: Relationship between tinnitus and severity of exposure to noise

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Rubak, T [28]	2008	752 workers employed in 91 workplaces. Tinnitus and no hearing handicap (n=67), Tinnitus and hearing handicap (n=50) and No tinnitus (n=635).	Average exposure in industrial trades was 83.7 dB(A)	Mean age (SD) in controls, those with tinnitus and hearing handicap, and those with tinnitus but no hearing handicap was 39.5 (9.1), 46.9 (7.8), 36.1 (7.1) years respectively	Investigated the odds ratio of tinnitus with and without concomitant hearing handicap. Hearing handicap was defined as an average hearing threshold for either ear at 2,3 and 4kHz above 20 dB. Could not find any increase in risk of tinnitus with actual noise level, duration of noise exposure (years) or cumulative noise exposure (dB(A)-years) in workers who did not have a hearing handicap. In workers who had a hearing handicap there was an increase in odds ratio for tinnitus with increasing cumulative noise exposure (p=0.03). However, although there was an increase in odds ratio with increasing noise level and duration of noise exposure these did not reach statistical significance.	This study suggests that tinnitus is only related to noise exposure if there is also hearing loss. The numbers in the tinnitus groups were small which meant that the confidence intervals for the odds ratios were wide, and thus other relationships did not reach significance. A strength of this study was that actual noise levels were obtained using personal dosimeters, and audiometry measurements were also obtained.
Hagberg, M [32]	2005	407 students enrolled at the School of Music and Music Education at Goteborg University	Grouped levels not given	Mean age for men was 35 (range 23-49) years and in women was 34 (range 24-57) years	Questionnaire based study. Found the highest incidence of symptoms was for reported tinnitus with a rate of 10.6 per 1000 years of instrumental practice. Impaired hearing (by questionnaire) had an incidence of 6.5 per 1000 instrument years. Reported an increased risk of tinnitus in those practicing for more than 20 hours per week prior to development of the symptoms. The relative risk was 1.59 (90% confidence interval of 0.94-2.70).	Suggests that noise exposure in musicians can lead to tinnitus and hearing impairment. However, hearing impairment was judged by questionnaire rather than audiometric measurements and no actual noise levels are reported.

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Sindhusake, D [31]	2003	2,015 individuals from the general population aged over 55 years of age in Sydney, Australia.	Grouped levels not given	Mean age of 69.8 years	When age and gender were taken into account, both the duration of noise exposure in years and the severity of work related noise exposure (self-reporting none/quiet, tolerable, unable to hear speech) were significant risk factors for tinnitus. When these and other factors (including hearing loss) were entered into a predictive model (in which each variable was adjusted for all the others) these factors were significant and demonstrated a dose-response. For example, the relative risk for those who reported that their work-related noise exposure was tolerable was 1.39 and for those who reported they were unable to hear speech it was 1.53. Overall, the study reports that work-related noise exposure may have caused 13.6% of tinnitus cases in this community.	This study shows that noise exposure leads to a greater risk of tinnitus in a dose dependent way. This was independent of hearing loss. This study was performed in an older age group from the general population. In this population work-related noise exposure may have caused 13.6% of tinnitus cases. However, it should be borne in mind that around 65% of this population were not exposed to significant noise levels.
Palmer, KT [30]	2002	12,907 individuals from the general population	Grouped levels not given	Between 35 and 64 years of age	Prevalence ratio for tinnitus increased with increasing years working in a noisy job (results adjusted for age). A noisy job was defined as that where they had to shout to be heard. For example, if they had worked for between 1 and 5 years in a noisy job the prevalence ratio was 1.8 and this increased to 2.6 in those who had worked for more than 10 years in a noisy job. The number of men in Great Britain who have tinnitus attributable to occupational noise exposure was estimated as 266,300 and the number of women was 84,000.	This study demonstrated a relationship between the prevalence of tinnitus and length of time of exposure to a noisy work environment in a general population. This was based upon self-reporting in a questionnaire based study, rather than actual noise measurements.

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Sulkowski, W [6]	1999	261 drop forge operators	Peak pressure level for impulse noise of 135.1 dB	Mean age 31.2 years	This study aimed to investigate the effect of impulse noise on tinnitus and hearing loss. As part of this publication, information on the prevalence of tinnitus and exposure duration was presented. Percentage of individuals with tinnitus increased with years of exposure. Prevalence percentages with years of exposure were 31.6, 65.5, 84.9, 95.1, 92.5 and 88.9% for exposure durations of 1-3, 3-5, 5-10, 10-15, 15-20, 20-25 years.	The prevalence of tinnitus was related to the exposure duration, but no statistical analysis was contained within this paper.
Sallustio, V [29]	1998	180 workers from two cement industries	Three groups exposed to <80 dB(A) (controls), between 80-85 dB(A) and those between 86-90 dB(A)	Mean 44.9 (range 21-63) years	Overall, 14.3% of workers had continuous tinnitus, which began more than one year before. There were slight differences in prevalence of tinnitus in the three noise groups (6.3%, 13.9% and 18.1% respectively) but these were not statistically significant.	Differences between groups with different noise exposures were non-significant.
Gunderson, E [27]	1997	31 employees (bar tenders, waiters and waitresses) from 8 live music clubs in New York	Average performance sound levels ranged from 94.9 to 106.7 dB(A). Ambient sound levels ranged from 83.7 to 97.1 dB(A).	Not reported	Found relationship between the number of individuals experiencing tinnitus after work and the noise levels in the clubs, with individuals working in the louder clubs experiencing the greater frequency of tinnitus (p=0.01).	Small study but does seem to suggest that the prevalence and frequency of symptoms of tinnitus following work is related to the noise level.

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
McShane, D P [17]	1988	3,466 claimants for noise induced hearing loss	No information regarding the actual noise levels, other than duration of exposure, is reported	Average age 60.5 (range 16-81) years	Investigated the relationship between the duration of occupational noise exposure (years) and the prevalence of tinnitus. Found that the prevalence of tinnitus was 33.7% in those exposed for between 0 and 10 years. This then rose to 54% in those exposed for 11-20 years, and then stayed relatively stable.	Suggests that after 10 years exposure the prevalence of tinnitus is independent of time of exposure.
Van Dijk, FJH [26]	1987	539 male workers in seven industries	Distribution of personal noise exposure levels was 13% <86dB(A), 28% 86-90 dB(A), 33% 91-95 dB(A), and 25% > 95 dB(A)	21% < 25 years, 31% 25-34 years, 33% 35-49 years, 9% 40-54 years, 6% 55-65 years	Report a weak relationship between noise exposure (L_{Aeq}) and tinnitus ($p<0.05$).	Authors suggest that the relationship between tinnitus and hearing loss is stronger than that between tinnitus and noise level. Individual data for the relationship between tinnitus and noise level are not presented in the paper.

3.3 QUESTION 2 – IS THERE A RELATIONSHIP BETWEEN TINNITUS AND HEARING LOSS IN THOSE EXPOSED TO NOISE AT WORK?

In order to establish whether there is truly a relationship between tinnitus and hearing loss we aimed to review the literature to address the following questions:

1. Is the prevalence of tinnitus in those with noise-induced hearing loss greater than than in those with normal hearing?

2. Are the hearing thresholds measured using audiometry greater in those with tinnitus as compared to those who do not have tinnitus?

3. Is there evidence of an increased risk of tinnitus in those with hearing loss, or an increased risk of hearing loss in those with tinnitus?

4. What is the temporal relationship between tinnitus and hearing loss?

3.3.1 Is the prevalence of tinnitus in those with noise-induced hearing loss greater than in those with normal hearing?

Evidence table three details the papers reviewed in this area. A total of 12 papers were identified in this area and they tended to fall into three main areas:

1. Those comparing the prevalence of tinnitus in those with or without noise-induced hearing loss

2. Those investigating a relationship between the severity of hearing loss and the prevalence of tinnitus

3. Those reporting the prevalence of tinnitus and noise-induced hearing loss in the same population

Two studies have compared the prevalence of tinnitus in populations with or without noise-induced hearing loss and have demonstrated an increase in prevalence of tinnitus in those with hearing loss [22, 30]. One study, which was a 15-year longitudinal study involving noise-exposed workers, found that the prevalence of tinnitus in workers with ≤10 dB hearing thresholds was 16% compared to 42% in workers with ≥15 dB hearing thresholds (p=0.005) [22]. Another study by Palmer, which used self-reported hearing difficulty as their measure of hearing loss, showed that the age standardised prevalence of persistent tinnitus was 16.1% in those who reported severe difficulties in hearing, as compared to 5% in those with slight or no difficulties in hearing [30].

Other studies have investigated the relationship between the severity of hearing loss and the prevalence of tinnitus [8, 12, 17, 19, 25, 26, 33]. One particularly large study involved 30,000 workers involved in a hearing conservation programme (similar to health surveillance) and found a clear non-linear exponential relationship between the prevalence of tinnitus and extent of hearing loss at all frequencies [12]. Another study suggested a linear relationship between the prevalence of tinnitus and the severity of hearing loss as defined by their audiometric categorisation. However this paper did not contain any statistical analysis, so the validity of these findings is difficult to

ascertain [33]. Other studies have also found an increase in the prevalence of tinnitus with increasing hearing loss [19, 25, 26]. However, two studies have failed to establish a relationship between these two factors [8, 17]. Both of these studies had quite large sample sizes, but only consisted of compensation claimants. Whether this has contributed to these findings is unclear.

Three studies reported both the prevalence of tinnitus and noise-induced hearing loss in the populations studied [14, 21, 23]. Two of these studies reported a greater prevalence of hearing loss compared to tinnitus [21, 23] whereas the other reported a greater prevalence of tinnitus [14]. In none of the studies were the prevalence of noise-induced hearing loss and tinnitus the same. These three studies were conducted in different populations (construction workers, disc jockeys and airline pilots), who would be likely to have different noise exposure characteristics.

Evidence table three – Prevalence of tinnitus with and without hearing loss

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Hong, O [21]	2006	623 construction workers	Mean (SD) 18.14 (10.93) years in construction.	Mean (SD) 42.96 (9.98) years.	38% of construction workers reported ringing or buzzing in the ear and 62% indicated having problems in understanding what people say in loud noise. Over 60% of workers showed hearing loss (hearing threshold ≥25dB) at 4 and 6kHz.	This study gives an overall prevalence of tinnitus but does not relate this to hearing loss.
Bray, A [14]	2004	23 disc jockeys.	Sound levels up to 108 dB(A) were recorded in nightclubs, with an average of 96 dB(A). No information on length of exposure.	Mean 29 (range 21-41) years	Three disc jockeys (13%) showed evidence of noise induced hearing loss. 74% reported tinnitus, with 12% experiencing this all of the time.	Small study. Presents some data to show a high prevalence of tinnitus in disc jockeys exposed to noise in nightclubs. The prevalence of noise induced hearing loss was much lower.

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Palmer, KT [30]	2002	12,907 individuals from the general population	Grouped levels not given	Between 35 and 64 years of age	Questionnaire based study with no hearing or noise measurements. Authors report that the self reports of tinnitus and hearing difficulties were strongly associated. In men, the age standardised prevalence of persistent tinnitus was 16.1% in those who reported severe difficulties in hearing, compared with 5% in those with slight or no difficulties of hearing. This difference was greater in women with 33.1% and 2.6% respectively.	This study was a general population questionnaire based study and showed that the prevalence of tinnitus was related to self-reported difficulties in hearing. This study relied upon self-reporting of hearing difficulties, rather than measurement of hearing thresholds using audiometry.
Begault, DR [23]	1998	64 commercial airline pilots	Not reported	Median age 53 (range 35-64) years	29.5% of pilots reported occasional or frequent tinnitus. The proportion reporting permanent hearing loss (confirmed by their doctor) was between 27 and 53%, depending upon their age.	The prevalence of hearing loss in this study was generally greater than the prevalence of tinnitus. This study did not present data showing the prevalence of tinnitus with or without hearing loss.

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Griest, SE [22]	1998	91 male employees working in noisy environment	85-101dB(A) for a minimum of 12 years	Age range of individuals at beginning of the study was 18-41 years.	This study was a 15-year longitudinal study. Looked at the maximum threshold shift in audiometric testing at 4000Hz over the 15-year period. Split into two groups according to maximum shift: ≤10dB or ≥15dB and compared to prevalence of reported tinnitus. Prevalence of tinnitus in ≤10dB (n=44) and ≥15dB (n=47) groups was 16 and 42% respectively (p=0.005).	This study demonstrated that the prevalence of tinnitus is greater in those with hearing loss (≥15dB at 4kHz). The study only looked at 4kHz. The strength of this study is that it is a 15-year longitudinal study of individuals within a hearing conservation programme.
Ylikoski, ME [19]	1994	786 Finnish army officers exposed to gunfire noise	Not reported	Mean 39.8 (range 25-61) years	42.5% of subjects reported that they experienced tinnitus either occasionally or continuously. The occurrence of tinnitus was related to the level of hearing loss. For example, those reporting continuous tinnitus was 2.2% in those with normal hearing, 2.7% with slight to moderate hearing loss (hearing threshold >20 dB and below 64 dB at some of frequencies from 3-8kHz and in low-frequency range <20 dB), 19.8% with severe hearing loss (hearing threshold ≥65 dB at some of frequencies from 3-8kHz and in low-frequency range <20 dB) and 25.5% with disabling hearing loss (hearing threshold of >20 dB at low frequencies). These data were not analysed statistically.	Study seems to show that tinnitus is related to hearing loss in those exposed to gunfire noise. Statistical significance of results unclear.

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Phoon, WH [25]	1993	647 noise exposed workers notified as cases of noise induced deafness	Mean (SD) duration of exposure was 170 (100.7) months in those with tinnitus and 160 (106) months in those without tinnitus	Mean age 39 years	Split into groups based upon average hearing loss level (AHL) at 1, 2 and 3kHz. 'Early' cases had AHL of ≤ 25 dB, 'intermediate cases' had > 25dB but < 50 dB, 'late' cases had AHL of ≥ 50 dB. There was an increase in prevalence of tinnitus between the 'early' and 'intermediate' cases (20% versus 30%), and the 'early' and 'late' cases (20% versus 27.3%) (p=0.02). 30% of sufferers reported that this interfered with daily activities e.g. telephone conversation.	This is a fairly large study involving a range of hearing loss in a fairly young population. It seems to suggest that tinnitus is related to hearing loss. However, it did not contain a group that did not have hearing loss.
McShane, D P [17]	1988	3,466 claimants for noise induced hearing loss	Mean exposure to workplace noise was 26.1 (SD 11.8) years	Average age 60.5 (range 16-81) years	Looked at the prevalence of tinnitus with 10 dB increments of hearing loss at 4 kHz. There was no relationship between the prevalence of tinnitus and extent of hearing loss in the right ear.	This study does not support the idea that there is a link between tinnitus and extent of hearing loss. This study did not include a control population without hearing loss and purely consisted of those claiming for hearing loss.
Alberti, PW [8]	1987	2,442 workers claiming compensation for hearing impairment	Mean exposure was 25.3 years	Mean age of 56 years	The data was split into 3 categories according to the average hearing loss (40 dB or less, 41-69 dB, and 70 dB or more). The prevalence of tinnitus in these three categories of hearing loss for the 'impulse noise' group was 67, 63 and 70% respectively. For the 'steady-state' noise group they were 48, 47 and 57% respectively.	This study was mainly descriptive and had no statistical analysis included. The authors conclude that impulse noise leads to a greater prevalence of tinnitus, but that tinnitus was not related to the extent of hearing loss.
Van Dijk, FJH [26]	1987	539 male workers in	Distribution of	21% < 25	Hearing loss defined as the largest loss at	This study suggests that there is a link

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
		seven industries.	personal noise exposure levels was 13% <86dB(A), 28% 86-90 dB(A), 33% 91-95 dB(A), and 25% > 95 dB(A)	years, 31% 25-34 years, 33% 35-49 years, 9% 40-54 years, 6% 55-65 years	3, 4, or 6 kHz for the left or right ear. Found that the prevalence of tinnitus was related to the extent of hearing loss. Workers with a hearing loss of ≤15 dB had a 7% group prevalence of tinnitus and those with 40 dB loss had a prevalence of 22% ($p<0.05$).	between hearing loss and occurrence of tinnitus.
Miyakita, T [33]	1986	362 male workers exposed to occupational impulsive noise	Mean duration was > 30 years	Mean 51.3 (range 48-53) years	This study looked at the classification of audiometric measurements, but as part of this they also presented data related to the prevalence of tinnitus and audiometry. They found that as the severity of hearing loss (according to categorisation) increased so did the prevalence of tinnitus. This appeared to increase in a linear way but no statistical analysis was presented, and it is not clear whether the differences in prevalence with severity are statistically significant.	Study suggests that there is a relationship between the prevalence of tinnitus and severity of hearing loss in noise exposed workers.

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Chung, DY [12]	1984	30,000 workers exposed to noise, involved in a hearing conservation programme	Mean of 85 dB(A) or more	Not reported	Investigated the relationship between the prevalence of tinnitus and level of hearing loss at different frequencies. Found a clear non-linear exponential relationship between prevalence of tinnitus and extent of hearing loss at all frequencies (0.5kHz to 8kHz). There was no clear independent effect of age upon the prevalence of tinnitus.	This large study focussed on those within hearing conservation programmes (cf health surveillance) and therefore involved a range of hearing levels. Study clearly demonstrated a relationship between an increase in prevalence of tinnitus and extent of hearing loss. Showed that any association between age and tinnitus was a consequence of the relationship between age and hearing loss.

3.3.2 Are the hearing thresholds measured using audiometry greater in those with tinnitus as compared to those who do not have tinnitus?

A total of 9 papers (evidence table four) were identified from the review, which compared the hearing thresholds measured in populations with or without tinnitus [3, 7, 11, 13, 15, 24, 25, 34, 35]. Eight of these publications showed that the group hearing thresholds in populations with tinnitus were higher than the thresholds measured in those without tinnitus [3, 7, 11, 13, 15, 24, 25, 35]. These studies have involved sample sizes ranging between 31 and 110,647 individuals. The smallest of these studies found that there was an increase in the hearing thresholds measured in those with tinnitus, but that this wasn't statistically significant, possibly because of the small sample size [35]. One further study, did not contain any statistical analysis, although it was conducted with a large sample size (6,804) [3]. This study reported that the mean hearing threshold in those without tinnitus was 15dB as compared to 25dB in those with tinnitus. This difference was even greater in those with self-reported hearing impairment, with hearing thresholds in those without and with tinnitus of 33dB and 53dB respectively. The remaining 6 studies that have shown a positive relationship between the hearing thresholds and tinnitus have shown statistically significant findings and have involved reasonable sample sizes [7, 11, 13, 15, 24, 25]. The study published by Phoon has also shown that the differences in hearing threshold between workers with or without tinnitus remain even when confounding factors such as gender, age, race and noise duration are taken into account [25]. Two studies have involved statistical analysis to investigate which factors are the most important in determining hearing loss, as measured by audiometry [11, 13]. Both of these studies showed that tinnitus was an important risk factor for the development of hearing loss [11, 13].

Only one study was found that did not support the evidence that hearing thresholds are higher in those with tinnitus [34]. In this study the total area under the curve of the audiogram was calculated as the total hearing loss. This was a small study focusing on compensation claimants with moderate to severe hearing loss. The overall hearing loss in the group with tinnitus was significantly lower than in the group who did not have tinnitus. The authors acknowledge that these findings contrast with the rest of the literature, but suggest that this could be explained by differing criteria use to define whether tinnitus is present.

Evidence table four – Hearing thresholds from audiometric measurement with or without tinnitus

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Muluk, N [35]	2008	Workers in a steel factory exposed to occupational noise. 16 male workers with tinnitus and 15 age-matched workers without tinnitus.	Noise levels varied between 73 and 110 dB.	Mean age for those with tinnitus was 42.2 (range 33-53) years. For the group without tinnitus it was 42 (range 34-53) years	Hearing thresholds were greater in those with tinnitus at all frequencies. These differences were not statistically significant.	Whilst there was a suggestion that those with tinnitus had greater hearing thresholds, these differences were not statistically significant. This may be because of the small numbers involved in the study.
Konig, O [34]	2006	71 compensation claimants with moderate to severe work-related noise-induced hearing loss in Germany. 30 without tinnitus, 24 with tone-like tinnitus and 17 with noise-like tinnitus.	Not reported	Mean age 56 (range 38-69) years	Calculated overall hearing loss as the area under the curve of the audiogram. Found that the overall hearing loss in those with tinnitus was significantly lower ($p=0.0006$) than in those who did not have tinnitus. When the audiograms were compared it was found that audiograms were similar between those with or without tinnitus at high and low frequencies, but differed over the mid-range. The groups without tinnitus showed the highest hearing thresholds.	This study is small compared to some of the others but does report statistically significant findings. The authors acknowledge that their results are different to other studies, and suggest that this may be the result of different choices of subjects and different inclusion criteria related to tinnitus. In particular, this study only included those with chronic tinnitus rather than those with intermittent problems.

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Chen, J-D [24]	2003	384 noise-exposed workers in an oil refinery	Exposed to average noise level of 73-89 dB(A) Mean duration of exposure was 14 (SD 7) years	Mean age 39 (SD 5) years	Those reporting tinnitus had significantly greater ($p<0.05$) hearing thresholds in both the low and high frequency ranges. In the low frequency range the mean (SD) hearing threshold was 18(11) dB in those reporting tinnitus and 15(8) dB in those without tinnitus. In the high frequency range the corresponding values were 35(21) dB and 24(14) dB.	This study suggests that those with tinnitus following noise exposure have greater hearing thresholds
Prasher, D [15]	2001	198 mill workers exposed to noise	85-95dB(A) for a mean of 12 years	Mean age (SD) for the group with tinnitus 47 (9) years and 39 (9) years for the group without tinnitus	Pure tone average hearing threshold across all frequencies (125Hz, 250Hz, 500Hz, 1kHz, 2kHz, 4kHz, 6kHz, 8kHz) was measured. Also measured transient evoked otoacoustic emissions. Those with tinnitus had a significantly raised hearing threshold compared to those without tinnitus. On average the hearing threshold was around 15 dB higher in the tinnitus group. They also had significantly reduced transient otoacoustic emissions of an average value of 2.6 dB.	This suggests that individuals with tinnitus have higher hearing thresholds than those without tinnitus.

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Phoon, WH [25]	1993	647 noise exposed workers notified as cases of noise induced deafness	Mean (SD) duration of exposure was 170 (100.7) months in those with tinnitus and 160 (106) months in those without tinnitus	Mean age 39 years	Hearing thresholds at high and low frequencies were significantly higher in those with tinnitus. These differences remained even when adjusted for sex, age, race and noise duration.	This is a fairly large study involving a range of hearing loss in a fairly young population. It does seem to suggest that tinnitus is related to hearing loss, however it did not contain a group that did not have hearing loss.
Neuberger, M [13]	1992	110,647 noise exposed workers .	>85 dB	Aged between 15-65 years	Found that individuals with ear disease, head injury or tinnitus had higher hearing thresholds on audiometry. Tinnitus appeared to be the most important symptom in predicting the increased hearing thresholds in individuals exposed to noise levels of 85-105 dB and those exposed between 105-125 dB.	This study suggests that tinnitus is an important factor in noise induced hearing loss. The population in this study was not pre-selected to include only those with hearing loss. It included all of those exposed to noise over 85 dB for a minimum of 6 months.

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Bauer, P [11]	1991	47,388 noise-exposed workers	Median 89.8 dB(A). Median length of exposure was 11.8 (range 0.5-45) years	Median age 36.1 years	Undertook weighted regression analysis to investigate risk factors for hearing loss at different frequencies 0.5 to 6 kHz. Biggest factor related to hearing thresholds was age. Tinnitus was related to hearing loss across the frequencies but was fairly constant across the frequencies. Reported that most important frequency related to noise emission is 4 kHz	This was a very large study and contained some fairly detailed mathematics. The study shows that tinnitus is related to noise induced hearing loss.
Kamal, AA [7]	1989	88 drop-forge workers	Exposed to impact noise ranging between 112 to 139 dB(A) at a rate between 20-50 drops per minute	Between 30-60 years of age	Found that workers reporting tinnitus had the highest hearing thresholds at all frequencies tested ($p<0.05$). The highest hearing threshold was measured at 6kHz. Reported 'difficulties in hearing the human voice' was significantly associated with reporting of tinnitus ($p<0.001$).	This study shows that there is a relationship between tinnitus and hearing loss following exposure to impulse noise. It is also apparent that this was having an impact on quality of life as tinnitus was associated with difficulty in hearing the human voice.

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Coles, RRA [3]	1981	6,804 individuals from the general population in four cities of the UK	32.3% reported noise exposure	38% <40 years 32.8% 40-60 years 29.2% >60 years	Found that the mean hearing threshold was greater when tinnitus was present. In the group with normal hearing and no tinnitus, the mean hearing threshold was 15 dB compared to 25 dB in the group with normal hearing and tinnitus. The group with self-reported hearing impairment and no tinnitus had a mean threshold of 33 dB with those with hearing impairment and tinnitus having the greatest threshold of 53 dB. It is unclear whether these findings are statistically significant as there are no statistics presented in this paper.	This study was published as a pilot study for a larger main study. This study shows that those who have tinnitus have greater hearing thresholds and thus more hearing loss than those without tinnitus.

3.3.3 Is there evidence of an increased risk of tinnitus in those with hearing loss, or an increased risk of hearing loss in those with tinnitus?

Only three papers (Evidence table five) were identified which reported odds ratios or relative risks linking hearing loss and tinnitus [24, 31, 36]. Two of these studies reported the risks of tinnitus in those with hearing loss [31, 36]. Sindhusake [31] reported a relative risk of 1.12 (95% confidence interval of 1.06-1.18) of tinnitus in those with hearing loss. This was statistically significant but only represents a small increase in risk. Another study reported that the odds ratio of tinnitus occurring in those with deafness was 1.11 (95% confidence interval 0.5-2.44) and not statistically significant [36]. However, a further study investigating the risk of developing hearing loss in noise-exposed workers reported that the presence of tinnitus increased the risk of developing hearing loss by 2-3 times [24].

3.3.4 What is the temporal relationship between tinnitus and hearing loss?

Only one study was identified which had sought to establish the temporal relationship between tinnitus and hearing loss [22]. This was a 15-year longitudinal study which involved workers in environments with average noise levels ranging between 85 and 101 dB(A) over the period of the study. Of the 91 workers involved in the study 27 reported tinnitus. Twenty of the individuals who reported tinnitus also had noise-induced hearing loss (as defined by a hearing threshold ≥ 15dB at 4kHz) and 90% of these had reported tinnitus prior to this change in hearing threshold. Although this study contains relatively small numbers of individuals reporting tinnitus the association between time of reporting of tinnitus and the time when hearing loss occurred was statistically significant (p=0.03). On average tinnitus occurred 5.8 years prior to the maximum hearing loss, with a range of 1-16 years.

Evidence table five – Studies presenting risk factors or odds ratios related to hearing loss and tinnitus

Author	Year	Type of subjects	Noise exposure	Age	Findings	Comments
Chen, J-D [24]	2003	384 noise-exposed workers in an oil refinery	Exposed to average noise level of 73-89 dB(A). Mean duration of exposure was 14 (SD 7) years	Mean age 39 (SD 5) years	The odds ratio for developing hearing loss in the low frequency range in those with tinnitus was 2.6 (95% confidence interval 1.3-5.5) and in the high frequency range was 3.0 (95% CI 1.9-4.9).	This study suggests that the risk of developing hearing loss if tinnitus is present is 2-3 times greater than if tinnitus is not present. However, other factors such as self-reporting of hearing loss gave much higher odds ratios.
Sindhusake, D [31]	2003	2,015 individuals from the general population in Sydney, Australia	Grouped levels not given	Mean age of 69.8 years	When age and gender were taken into account hearing loss (10 dB) at 0.5, 1, 2 or 4 kHz was found to be a significant risk factor for tinnitus (relative risk of 1.12 – 95% confidence interval 1.06-1.18). Produced a predictive model for tinnitus, which included degree of hearing loss. However, hearing loss only had a modest association with tinnitus – 11% increased likelihood of reporting tinnitus with each 10 dB increase in hearing threshold.	Study shows that in this older age group hearing loss is a predictive factor for reporting of tinnitus. However, the risk was quite small and other factors (e.g. noise exposure) were more important.
McBride, D [36]	1993	189 workers in a mining colliery	Mean duration of exposure 9.8 years	Not reported	Deafness was determined by audiometry as outlined by the HSE document 'Audiometry in Industry'. The odds ratio of tinnitus occurring in those with deafness was calculated as 1.11 (95% confidence interval of 0.5-2.44).	This study did not show an obvious increased risk of tinnitus in those with hearing loss.

4 MAIN FINDINGS AND DISCUSSION

The main issues addressed by this review are:

1. Is there a relationship between exposure to noise at work and tinnitus?

2. Is there a relationship between tinnitus and hearing loss in those exposed to noise at work?

In order to address these questions an extensive search of 12 different databases, from as early as 1951, was conducted to identify publications relevant to this review. However, even following this extensive search only 34 publications were identified that were written in the English language and were relevant to the questions posed by this review. Therefore, there does not appear to be a vast body of knowledge available investigating these issues. If the scope of the search had been widened to include noise in general, rather than specifically occupational noise exposure, then it is possible that more publications would have been identified. However, it was felt that the focus of this review should be on occupational noise rather than noise in general. The 34 publications identified have been reviewed in detail and form the basis of the main findings in this report.

4.1 IS THERE A RELATIONSHIP BETWEEN EXPOSURE TO NOISE AT WORK AND TINNITUS?

In order to address this question the information in the published literature could be split into references that provided information regarding the prevalence of tinnitus in populations exposed to noise at work, and references investigating the relationship between tinnitus and the severity of noise exposure. Ideally to answer the question of whether occupational noise exposure leads to tinnitus one would also need information on a control group, who are not exposed to occupational noise, to act as a comparison. However, only four studies were identified that also contained information regarding the prevalence of tinnitus in a non-noise exposed population [3-6]. The relative prevalence reported for tinnitus in noise-exposed populations compared to controls were 70.4% vs 3.5%, 32.2% vs 6.7%, 24% vs 14.4% and 12% vs 2% respectively. Therefore, these four studies would suggest that the prevalence of tinnitus in workers exposed to noise at work is higher than in control non-noise exposed populations.

Overall, in all of the studies that reported some prevalence of tinnitus in populations exposed to occupational noise the prevalence was widely variable (between 87.5% and 5.9%). Factors such as the type of participant (e.g. compensation claimants vs health surveillance), the type of noise an individual is exposed to (e.g. impulsive vs continuous) and the definition of tinnitus used (i.e. whether transient tinnitus is excluded) may all contribute to the prevalence measured in any given population. In addition, if noise-induced hearing loss is related to tinnitus, then the level of noise-induced hearing loss within the studied population will in turn affect the measured prevalence of tinnitus. In general, it does appear that the prevalence of noise-induced hearing loss (where reported) was higher in those studies with the highest prevalence of tinnitus. Interestingly, three studies that had particularly large sample sizes of noise-exposed workers (110,647, 30,000 and 47,388 respectively) had the lowest reported prevalence of tinnitus of 6.7%, 6.6% and 5.9% respectively. Unfortunately, two of the studies did not report the prevalence of noise-induced hearing loss in the studied population and one reported that around 10% had some impairment.

There have been a few studies that have reported the prevalence of tinnitus within the general population [37-40]. These studies suggest a range of prevalence between 14.2% and 33%. In the literature detailed in evidence table one 11 of the studies reported a prevalence of tinnitus greater than 33% and 10 below.

Some studies have aimed to look at the relationship between tinnitus and the severity of exposure to noise, rather than simply whether they have been exposed to noise at work or not. These studies have either quantified noise exposure using actual noise measurements [26-29] or estimated exposure based upon the total number of years working in a noisy environment [6, 17], and difficulty in hearing or speaking in that environment [30, 31]. There was only a small amount of literature published in this area (9 papers) but the majority of these studies show some relationship between severity of exposure and tinnitus [6, 17, 26, 27, 29-32]. Rubak [28] published a study involving 752 workers that involved the use of actual cumulative noise exposure derived from personal dosimeters. They found that tinnitus was only related to noise exposure if there was also hearing loss present (defined from audiometry). However, the numbers with tinnitus were small and the confidence intervals wide, which may have affected the outcome. Another study involving 180 workers from the cement industry found that the prevalence of tinnitus had a tendency to increase with the actual noise level but these differences were not statistically significant [29]. Two large studies conducted with the general population have shown relationships between working in a noisy job and tinnitus [30, 31]. Sindhusake et al conducted a study in 2,015 individuals over the age of 55 years in Sydney [31]. They constructed a predictive model for tinnitus taking account of age, gender and noise-induced hearing loss, and found that the relative risk of tinnitus increased with both the number of years of noise exposure and the severity in terms of the self-reported tolerability of the noise level. Whilst this study was conducted in an older population, a study carried out in the UK general population found similar findings in a population aged between 35 and 64 years [30].

Overall, the literature related to the relationship between exposure to noise at work and the prevalence of tinnitus suggests that the prevalence of tinnitus is greater in workers exposed to noise and that it is greater in those workers exposed for greater durations or to greater levels. However, the relative contribution of confounding factors, including the definition of tinnitus used and the prevalence of noise-induced hearing loss, are difficult to untangle from the published literature.

4.2 IS THERE A RELATIONSHIP BETWEEN TINNITUS AND HEARING LOSS IN THOSE EXPOSED TO NOISE AT WORK?

The literature identified in this area tended to address this question in two different ways:

1. It compared the prevalence of tinnitus in those with or without noise-induced hearing loss, or different severities of hearing loss and;

2. It compared the hearing thresholds in those with or without self-reported tinnitus.

Overall, nine papers were identified which addressed the first of these issues. Of these papers the majority (n=7) appeared to show a positive relationship between the prevalence of tinnitus and hearing loss [12, 19, 22, 25, 26, 30, 33]. However, whilst two of these studies do appear to report data to support this association they did not contain any statistical analysis, so the statistical validity of their findings is unclear [19, 33]. The remaining studies contain populations ranging between 91 and 30,000 workers. The largest of these studies was conducted within a hearing conservation programme (similar to health surveillance) and involved workers exposed to noise at a mean level of 85dB(A) or more[12]. This study reported that there was a non-linear

exponential relationship between the prevalence of tinnitus and the extent of hearing loss at frequencies between 0.5 and 8kHz.

Two studies did not report an association between the prevalence of tinnitus and severity of hearing loss [8, 17]. These were large studies that contained workers with significant noise exposure, and thus it is unclear why these studies did not find a positive relationship. However, one possible consideration is that these were the only studies that involved claimants for noise-induced hearing loss, and the impact of this on the self-reporting of tinnitus is unclear.

Nine papers were identified which investigated the impact of tinnitus on the actual hearing thresholds as measured by audiometry [3, 7, 11, 13, 15, 24, 25, 34, 35]. Six of these publications demonstrated a significant relationship between hearing thresholds and tinnitus [3, 7, 11, 13, 15, 24, 25]. Some of these studies have conducted group comparisons of the hearing thresholds in individuals with or without tinnitus, and demonstrated that the hearing thresholds in those with tinnitus are significantly higher [3, 7, 15, 24, 25]. Other studies have investigated tinnitus as a factor predicting hearing thresholds in regression analysis, and found that it is an important risk factor [11, 13]. The studies investigating the relationship between tinnitus and hearing thresholds found that the measured hearing thresholds at all frequencies (0.5 to 8kHz) are increased in those with tinnitus [7, 11, 15, 24, 25]. These differences appear to remain even when confounding factors such as sex, age, race and noise duration are taken into account [25]. These studies consisted of a range of sample sizes from relatively small (n=88) [7] to very large (n=110,647) [13], and have involved noise-exposed workers, cases of noise induced deafness and the general population. Three of the published studies did not report an association between hearing thresholds and tinnitus. One of these studies reported that the hearing thresholds were higher in those with tinnitus. However, this was not statistically significant [35]. This was a very small study involving 16 workers with tinnitus and 15 without tinnitus, and thus may not have had the power to detect a significant effect. Another study reported elevated values in tinnitus, but did not contain any statistical analysis [3]. The third study involved 71 compensation claimants with noise-induced hearing loss and found that the overall hearing loss, as assessed by measuring the area under the curve of the audiogram, in those with tinnitus was significantly lower than in those who did not have tinnitus [34]. The authors acknowledge that these results are contrary to much of the other published literature and possibly factors such as type of subjects and the definition of tinnitus used may have contributed to this difference.

Other studies have tried to establish the risk factors for the development of hearing loss or the occurrence of tinnitus [24, 31, 36]. One study reported that the odds ratio for developing hearing loss in those with tinnitus was between 2-3 times greater than if tinnitus was not present [24], whereas another study suggested that there was no increased risk of tinnitus occurring in those with deafness [36] . However, it does appear that reporting of hearing loss is a modest predictive factor for the occurrence of tinnitus [31].

Overall, the weight of the evidence that is available in the literature supports the hypothesis that there is a link between hearing loss and tinnitus. However, it is far from clear whether hearing loss and tinnitus occur as independent effects of noise exposure, or whether one is causally related to the other. The majority of the studies published are cross-sectional in nature and thus do not help to give information on the temporal relationship between these two health outcomes. However, there is one longitudinal study published that helps to provide some information on this issue[22]. This study was a 15-year longitudinal follow-up study that involved 91 noise-exposed workers. It was found that 90% of workers with both tinnitus and hearing loss had tinnitus on average 5.8 years before hearing loss took place. Whilst this does not necessarily show that tinnitus is causally related to hearing loss, it does suggest that where they both occur, tinnitus does tend to occur earlier and may be an earlier indicator of potential problems. However, the fact that the prevalence of tinnitus appears to be related not only to whether

hearing loss occurs, but also its severity, it would suggest that there may be some causal link. To fully understand this more research is required in this area.

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A review of the current state of knowledge on tinnitus in relation to noise exposure and hearing loss

This report details the results of a search of the published peer-reviewed literature investigating the relationship between tinnitus (ringing or buzzing in the ears), noise exposure at work and noise-induced hearing loss. A total of 12 citation databases (earliest date 1951) were searched which identified 252 publications, of which 34 were found to be relevant to the review. A number of studies have reported the prevalence of tinnitus in populations exposed to noise at work to be between 87.5% and 5.9%. Factors such as the type of participant (eg health surveillance, compensation claimant), the characteristics of the noise exposure and the definition of tinnitus used may contribute to this variability. Furthermore, four studies have shown that the prevalence of tinnitus in workers exposed to noise at work is significantly greater than in workers not exposed to noise. The majority of the published papers support the idea that there is an association between tinnitus and noise-induced hearing loss. The prevalence of tinnitus in those with hearing loss appears to be greater, and the hearing thresholds in those with tinnitus are higher. There is also a suggestion from one 15-year longitudinal study that tinnitus may be an early indicator of risk of the development of noise-induced hearing loss.

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