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The Effective Strategies to Prevent Noise-Induced Hearing Loss: A Systematic Review

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Noise-induced hearing loss (NIHL) is one of the highest recorded occupational diseases, despite being preventable. This paper reports on the initial part of a major interventional study on the effectiveness of a hearing conservation programme for the prevention of NIHL. The purpose of this systematic review was to assess the evidence for effective workplace interventions to prevent NIHL among workers exposed to hazardous noises at the workplace, which can be used in the development of future noise prevention and mitigation strategies. A systematic search was conducted in PubMed, Scopus and CINAHL for studies published from 1 January 2007 to 31 December 2016, while reviewing relevant textbooks and references from the studies selected. Only quantitative studies published in English that reported on interventions to prevent NIHL among adult workers were included in this review. The systematic literature search generated 203 records, and 29 full-text articles were reviewed. Nine studies from various regions were included in this review. The interventions identified in the prevention of NIHL were grouped into three strategies, the multifactorial approach or a combination of strategies, championed by leaders and one-off training. A comprehensive multifactorial intervention that combines multiple strategies is the method of choice for the prevention of NIHL.

Keywords: noise-induced hearing loss; vector control worker; occupational exposure

I. INTRODUCTION

Despite being a preventable occupational disease, noise-induced hearing loss (NIHL) remains a highly prevalent occupational disease, with an estimated annual incidence of 1.6 million per year, accounting for 16% of hearing loss in adults worldwide. NIHL is also of great public health importance globally due to a high disease burden, with over 4 million disability-adjusted life years (DALYs) and its economic impact, with an average of 0.2–2% of gross domestic products (GDP) in developed countries (Dobie, 1995, 2008; Leigh *et al.*, 1999; Nelson *et al.*, 2005; Cruickshanks *et al.*, 2012; Kirchner *et al.*, 2012).

NIHL is a form of high frequency, sensorineural hearing loss due to irreversible damage to stereocilia of the hair cells, within the cochlea, caused by excessive noise (Rabinowitz, 2000; Le Prell *et al.*, 2007). The criteria for occupational NIHL varies between different organisations and countries, with some focusing on the lower frequencies at 0.5–2 kHz and others giving greater weightage to hearing loss at higher frequencies, such as 3–6 kHz (Rabinowitz, 2012; Lie *et al.*, 2016). The classical audiometric notch seen in NIHL also shows variation depending on the type of noise exposure, for instance, a notch at 4 kHz for continuous noise, as well as notches at 6 kHz for impulsive noise and at 3 kHz for low frequency noise (Rosler, 1994; McBride and Williams, 2001).

NIHL has been attributed to daily exposure to average noise levels above 90 dB(A). In general, exposure to noise levels greater than 85 dB is considered to pose a risk for hearing loss, and preventive or control measures need to be taken. The permissible exposure limit varies according to regions, with the most developed and first world countries choosing 85 dB, while developing countries set a higher permissible exposure limit (PEL) at 90 dB for an eight-hour

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time-weighted average (TWA). Hence, the US Department of Labour, and most global noise regulations, require the implementation of hearing conservation for workers exposed to more than 85 dB(A) for an 8-hour work day (Clark and Bohne, 1999; Kurmis and Apps, 2007; Azizi, 2010).

Besides the direct effect noise has on hearing, its non-auditory effects on health have long been studied, and evidence suggests that noise exposure leads to annoyance, sleep disturbance and stress (van Dijk, Souman and de Vries, 1987; Muzet, 2007; Basner *et al*., 2014). Physiological evidence suggests there is also a risk of cardiovascular diseases as a result of raised heart rate and blood pressure, as well as peripheral vasoconstriction (Smith, 1991; Münzel *et al*., 2014; Skogstad *et al*., 2016). The workers' performance and concentration are also affected by exposure to noise, which leads to a higher incidence of workplace injuries and accidents (Stansfeld and Matheson, 2003; Banbury and Berry, 2005). Adverse pregnancy outcomes, such as small for gestational age due to intrauterine growth retardation and preterm delivery, are also associated with exposure to noise (Meyer, Aldrich and Easterly, 1989; Hartikainen *et al*., 1994; Committee on Environmental Health, 1997).

The objective of this systematic review was to evaluate effective interventions used to prevent NIHL among adult workers, 19 years of age or older, who were exposed to hazardous noises at the workplace, which can be used to develop future noise prevention and mitigation strategies, including effective hearing conservation programmes. Despite the known implications of NIHL on health, safety, cost and productivity, the evidence of effective strategies to prevent NIHL and determination of the effect of existing hearing conservation programmes on preventing NIHL are lacking.

II. MATERIALS AND METHOD

A. Inclusion and Exclusion Criteria

This systematic review was registered in the PROSPERO database of reviews with the registration number CRD42017064644 and was made available at https://www.crd.york.ac.uk/PROSPERO. The criteria for selected studies were quantitative studies that were published in English and published as journal articles only. The articles were scientific literature published within the past 10 years from 1 January 2007 to 31 December 2016. The study population includes adult workers, 19 years of age or older, exposed to noise levels above 80 dB(A). There was no limitation on the setting, thus studies from all regions of the world were included in this review. All studies that involved animals or were qualitative in nature were excluded, including letters to the editor and comments. This review included interventions that aimed to prevent NIHL at the workplace and consisted of at least one of the following components:

- Engineering controls: Performing noise exposure monitoring and reducing or eliminating the noise from the source based on exposure monitoring results
- Administrative controls: Training and educational programmes, organisational or management policies and supervision
- Hearing surveillance for workers, including audiometric testing
- Use of hearing protection devices

The measured outcomes used to evaluate the effect of the intervention studies in preventing NIHL included noise exposure levels, hearing threshold levels (audiometry testing) and workers perception and acceptability of the intervention.

B. Search Methods

A systematic evidence-based search of scientific literature was conducted in PubMed, CINAHL and Scopus for studies published within the past 10 years from 1 January 2007 to 31 December 2016, while reviewing relevant textbooks and references from the studies selected. These databases were selected as they are widely used among allied health professionals and easily accessible. PubMed was selected as it is easily accessible and covers a wide range of Health/Medical subjects. CINAHL database was included because it is commonly used among healthcare professionals. Scopus was included for its extensive peer-reviewed literature and scientific journals. A search strategy was developed using search terms found to have sensitivity and specificity in identifying occupational health intervention researches (Verbeek *et al*., 2005), keywords to identify studies on lowering levels of noise exposure and preventing hearing loss and additional concepts of specific interest to this literature review. In the databases, a combination of indexed keywords and free text words were used to search. To minimise irrelevant results, the terms were searched in title fields only. The search was completed in June 2017 and was limited to scientific peer-reviewed literature, published in English over a 10-year period up to 31 December 2016.

C. Data collection and quality assessment

Authors independently reviewed the titles and abstracts and rejected those viewed irrelevant. Full articles were recovered for articles that met the inclusion criteria of this review. For each study included, data was extracted, and risk of bias was assessed by the authors independently. Discrepancies in search results and quality assessment were resolved by discussion among authors. The quality of the evidence extracted on strategies to prevent NIHL was evaluated using a body of evidence matrix as outlined by the "National Health and Medical Research Council (NHMRC) 2009 levels of evidence and grades for recommendations for developer of guidelines" (Australian Government, 2009). The studies were graded excellent, good, satisfactory or poor based on five components; evidence base, consistency, impact, generalisability and applicability. This tool allows for the appraisal of the internal validity of the studies, including consistency and potential impact of the intervention. Additionally, this tool also takes into consideration external factors that may influence generalisability to the target population and applicability to the Malaysian health care system.

III. RESULT

The systematic search from three electronic databases yielded 203 articles. References were screened for eligibility and resulted in 184 full-text articles after 19 duplicate articles were removed. After screening the titles, 75 articles were shortlisted, of which 46 articles were excluded, after screening the abstracts, for not having any one of the three outcomes of interest (noise exposure, noise-induced hearing loss and perception and acceptability of intervention by worker/employee) or the desired study design. As a final point, 20 out of the 29 remaining articles were excluded based on a screening of the full text and critical reading. Hence in this review, we included the results of nine studies on the effective strategies to prevent NIHL. The flowchart in Figure 1 shows the details of the search and reasons for the exclusion of articles, and Table 1 provides the list of articles included in this review.

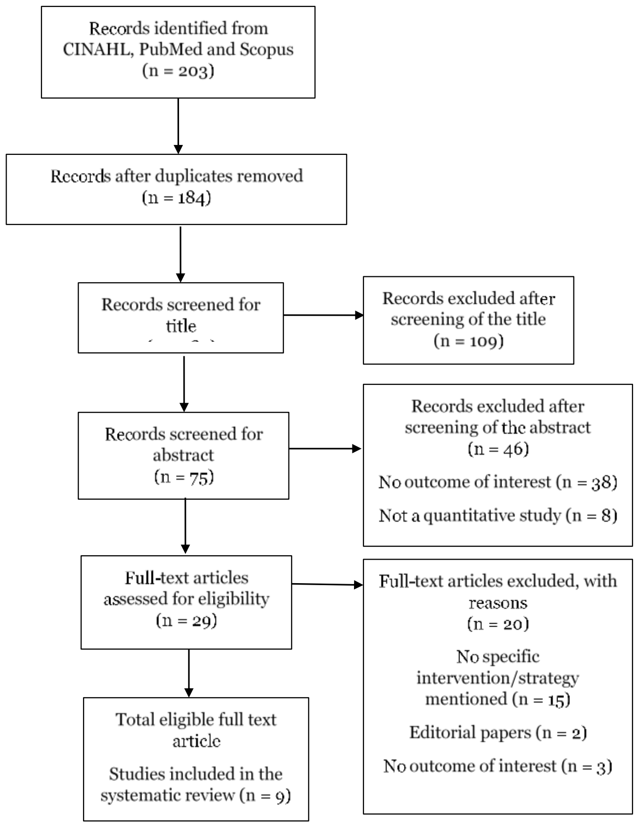

Figure 1. Flowchart of how articles were retrieved

Table 1. Articles included in the systematic review (n = 9)

Author(s)	**Year**	**Publications specification**
Williams, W., Brumby, S., Calvano, A., Hatherell, T., Mason, H., Mercer-Grant, C. and Hogan, A.	2015	Farmers' work-day noise exposure. *Australian Journal of Rural Health*, *23*(2), 67–73.
McTague, M.F., Galusha, D., Dixon-Ernst, C., Kirsche, S.R., Slade, M.D., Cullen, M.R. and Rabinowitz, P.M.	2013	Impact of daily noise exposure monitoring on occupational noise exposures in manufacturing workers. *International journal of audiology*, *52*(1), S3–S8.
Rocha, C.H., Santos, L.H.D., Moreira, R.R., Neves-Lobo, I.F. and Samelli, A.G.,	2011	Effectiveness verification of an educational program about hearing protection for noise-exposed workers. *Jornal da Sociedade Brasileira de Fonoaudiologia*, *23*(1), 38–43.
McCullagh, M.C.	2011	Effects of a low intensity intervention to increase hearing protector use among noise-exposed workers. *American journal of industrial medicine*, *54*(3), 210–215.
Seixas, N.S., Neitzel, R., Stover, B., Sheppard, L., Daniell, B., Edelson, J. and Meischke, H.	2011	A multi-component intervention to promote hearing protector use among construction workers. *International journal of audiology*, *50*(1), S46–S56.
Rabinowitz, P.M., Galusha, D., Kirsche, S.R., Cullen, M.R., Slade, M.D. and Dixon-Ernst, C.	2011	Effect of daily noise exposure monitoring on annual rates of hearing loss in industrial workers. *Occupational and environmental medicine*, 414–418.
Takahashi, K., Kawanami, S., Inoue, J. and Horie, S.	2011	Improvements in Sound Attenuation Performance with Earplugs Following Checklist-based Self-practice. *Journal of* University of Occupational and Environmental Health, *33*(4), 271–282.
Riga, M., Korres, G., Balatsouras, D. and Korres, S.	2010	Screening protocols for the prevention of occupational noise-induced hearing loss: the role of conventional and extended high frequency audiometry may vary according to the years of employment. *Medical Science Monitor*, *16*(7), CR352–CR356.
Davies, H., Marion, S. and Teschke, K.	2008	The impact of hearing conservation programs on incidence of noise-Induced hearing loss in Canadian workers. *American journal of industrial medicine*, *51*(12), .923–931.

C. Study Characteristics

1. Design Methodology

Table 2 provides information on the study designs, characteristics of the participants and outcome measures, as well as the results of the studies included in this systematic review. An overview of the empirical evidence and methodological quality of effectiveness of the studies will follow in the discussion section.

Table 2. Characteristics of included studies

Author/ Year	Design	Participants	Interventions	Outcomes	Notes
Williams *et al.*, 2015	Cross sectional	Farmers; n = 85; Australia	Championed by leaders: Noise exposure assessment and noise audit report booklet	Effectiveness/relevance of the noise audit report assessed using a short questionnaire (seven questions).	Comparability: Age: ?
McTague *et al.*, 2013	One group pre- and post-test	Workers from aluminium smelter and turbine component manufacturing factories; n = 127; USA	Championed by leaders: Voluntary use of daily noise exposure monitoring device consisting of a dosimeter equipped with visual cautioning alarms to alert workers when exposed to excessive noise.	Daily noise exposure levels and change in noise exposure over time in decibels (dB)	Comparability: No control group, blinding and randomisation
Rocha *et al.*, 2011	RCT	Hospital staff; n = 78; Brazil	One-off training: Educational training in the form of graphic material on noise-induced hearing loss (NIHL) including use and care of hearing protectors	Knowledge, attitude and practice towards noise (comparison before and after intervention) measured using a scoring questionnaire.	Comparability: Age: ? Job sector of participants and follow-up period not mentioned
McCullagh *et al.*, 2011	One group pre- and post-test	Farmers; n = 32; USA	One-off training: Model-based mailed intervention consisting of hearing protectors and instructions of use	Use of hearing protection devices.	Comparability: Age: ? Short term follow-up: 2–3 months
Seixas *et al.*, 2011	Both cluster and individually randomised RCT	Construction workers from various trades; n = 176; USA	Multifactorial intervention: Many comparisons possible, but we chose to compare two interventions considered to be the most relevant for practice. Intervention 1: Baseline training plus noise 'toolbox' onsite training (n = 44) Intervention 2: Baseline training plus noise 'toolbox' onsite training plus personal noise level indicator (n = 41) Control: Baseline training (n = 46)	Noise level measured as Laeq at two- and four-month follow-up	First baseline training, then cluster-randomised to tool-box; then individuals were randomised to noise level indicators or no indicators
Rabinowitz *et al.*, 2011	CBA/ ITS (authors provided additional data for ITS analysis)	Various workers of an aluminium smelter; n = 312; USA	Multifactorial intervention: Daily noise exposure monitoring and regular feedback on exposures from supervisors. Control: On-going hearing conservation programme (regulation mandated hearing tests, noise measurements, training)	Median TWA ambient noise exposures; median and range of noise exposures inside hearing protection (intervention group); high frequency hearing threshold levels (2, 3, 4 kHz); annual rate of hearing loss (dB/year)	Comparability: (matched on age, gender and hearing) Age: similar age (within 5 years); Intervention mean 48.7 years; control mean 48.6 years Hearing: controls matched (C1) and highly matched (C2): C1: baseline hearing = similar high frequency hearing threshold levels (binaural average of 2, 3 and 4 kHz) (within 5 dB) (n = I 78/C 234) C2: baseline hearing and initial rate of hearing loss during pre-intervention period (n = I 46/C 138)
Takahashi *et al.*, 2011	One group, pre- and post-test	Medical students from a university	Multifactorial intervention:	Changes in sound attenuation of	Comparability: Age: ?

		school of medicine; n = 10; Japan	Individual training on earplug use and checklist based self-practice.	earplugs and standard deviation pre- and post-intervention.	Small sample size with participants being highly educated and we versed with dangers of noise
Riga *et al.*, 2010	Prospective cohort study	Workers in food processing plant; n = 151; Greece	Multifactorial intervention: Noise exposure assessment and extended high frequency (EHF) audiometry	Shift or changes in hearing threshold.	Comparability: All groups matched for exposure to tobacco smoke
Davies *et al.*, 2008	CBA	Lumber mill workers; n = 22 376; Canada, British Columbia Intervention: Hearing conservation programme; n = 16,347 Control: those exposed to less than 80 Db-years plus those at their first hearing test following baseline; n = 6002 estimated from the number of person-years of 41,357 with a 6.8-year follow-up	Multifactorial intervention: Hearing conservation programme (HCP)	Standard threshold shift (STS): 10 Db or greater at 2, 3 or 4 kHz in the better ear.	Comparability: Proportional hazards model to adjust for age and hearing ability at baseline

*CBA = Controlled before-after study; ITS = Interrupted time-series; RCT = randomised controlled trial; ? = No data available

All nine of the included studies used quantitative methodologies. Two of the studies were championed by leaders (McTague *et al.*, 2013; Williams *et al.*, 2015), two were one-off trainings (McCullagh, 2011; Rocha *et al.*, 2011) and another five were multifactorial interventions (Davies, Marion and Teschke, 2008; Riga *et al.*, 2010; Rabinowitz *et al.*, 2011; Seixas *et al.*, 2011; Takahashi *et al.*, 2011).

2. Study Design

Two studies applied a controlled before-after (CBA) study design, with Rabinowitz *et al.* using interrupted time series (ITS) for additional data analysis (Davies, Marion and Teschke, 2008; Rabinowitz *et al.*, 2011). Two other studies used a randomised controlled trial (RCT) design, where Seixas *et al.* applied both cluster and individual randomisation (Rocha *et al.*, 2011; Seixas *et al.*, 2011). Three studies applied a one-group pre- and post-test design without a control group (McCullagh, 2011; Takahashi *et al.*, 2011; McTague *et al.*, 2013). In the remaining studies, Williams *et al.* included a cross sectional design and Riga *et al.* conducted a prospective cohort study comparing Extended High-Frequency (EHF) versus Conventional Audiometry (Riga *et al.*, 2010; Williams *et al.*, 2015). The smallest sample size among the nine studies included in this review was 10 university students from a university school of medicine (Takahashi *et al.*, 2011) and the largest sample size was 22,376 lumber mill workers (Davies, Marion and Teschke, 2008). These studies included a wide range of job sectors, including manufacturing, lumber mill, farm, food processing, hospital, construction, smelting industry and university students.

IV. DISCUSSION

A. Identification of three key noise-induced hearing loss (NIHL) prevention strategies

The programmes or interventions identified to prevent NIHL were heterogeneous in study design, outcome measures, geographical areas and job sectors, thus ruling out a statistical meta-analysis. Three key strategies for NIHL prevention were identified: championed by leaders, one-off training and multifactorial intervention (combination of multiple strategies). This section provides an overview of the evidence from the systematic evidence-based reviews of various occupational health interventions and the effectiveness of these interventions in the prevention of NIHL. The role of leadership in prevention of NIHL was supported by evidence of a 4% reduction in the percentage of daily noise exposure (McTague *et al.*, 2013). In another study, more than 95% of participants found the intervention to raise knowledge and awareness towards noise (Williams *et al.*, 2015). The one-off training strategy showed an increase in safety practice mainly use of hearing protectors by 44% post-intervention (McCullagh, 2011). Besides that, this strategy also improved workers knowledge and awareness towards hearing and noise with an increase of 19% in percentage score (Rocha *et al.*, 2011). Meanwhile, a combination of multiple strategies also proved effective in NIHL prevention by reducing the risk of standard threshold shift (STS) by 51% and reducing the average rate of hearing loss by 0.5 dB/year (Davies, Marion and Teschke, 2008; Rabinowitz *et al.*, 2011). A screening protocol using an Extended High Frequency (EHF) audiometry was effective in early detection of NIHL especially during the first decade of employment (Riga *et al.*, 2010). In relation to hearing protection devices, studies reported increased use of hearing protectors by 24% and up to 4 dB improvement in sound attenuation (Seixas *et al.*, 2011; Takahashi *et al.*, 2011).

1. Strategy 1: Championed by leaders

Two studies looked into the importance of external leadership and workplace management in the effective remodelling or implementation of change (McTague *et al.*, 2013; Williams *et al.*, 2015). The impact of the interventions in both studies were moderate to high, as improvements were demonstrated in noise exposure levels such as perceptions towards noise, the number of noise control measures in place and non-statistical descriptions of improved noise exposure. However, there is still a lack of studies showing the effectiveness of this approach in terms of reduction in NIHL cases or maintained hearing threshold levels as measured by audiometry testing. Both leadership intervention studies were conducted in different sectors, farming and manufacturing industries.

The study by Williams *et al.* showed that feedback from superiors using a noise audit report consisted of the following information: findings of the noise exposure assessment with explanations and methods to reduce exposure to excessive noise was effective in raising awareness among farmers and noise exposure management (Williams *et al.*, 2015). This study was part of a larger NHMRC project known as the Sustainable Farm Families (SFF) programme, coordinated by the National Centre for Farmer Health at Deakin University, which intended to improve the health, well-being and safety of farm families.

Williams *et al.* (2015) investigated farmers' noise exposure levels and evaluated the effectiveness of an on-farm noise audit report in improving awareness and promoting preventive attitudes towards farm-based noise hazards. The feedback given by supervisors in the form of a noise audit report included the following: A noise exposure assessment of daily activities through dosimetry; measurements of noisy tasks and machinery; supply and interpretation of a noise audit report. In addition to the noise report audit, participants were furnished with a personalised noise booklet to meet individual farm needs outlining noise levels, the acceptable duration of exposure, an explanation of their meaning/implication(s) and brief suggestions about how to reduce noise exposure. The results clearly showed that men and women shared an almost equal risk of exposure. The average noise exposure was 85.3 dB for an 8-hour TWA, which was above the recommended Australian exposure standard of 85 dB. Therefore, of those measured, 51%, and by estimation, more than 160,000 Australian agricultural workers are exposed to noise levels greater than the recommended standard, putting them at risk from hazardous noise. More than 95% of participants found the intervention to be effective in enhancing knowledge and awareness towards noise while motivating them to use hearing protectors. This evidence is supported by the Health Belief Model (HBM) that attempts to predict health behaviours where information provided by the leaders/supervisors improves the farmers' knowledge with regards to perceived susceptibility and severity of damaging noise, as well as perceived benefits of applying preventive behaviour at work (Rosenstock, 1974). Given this adequate information, it will promote awareness and a positive safety climate within the organisation, including reinforcing the need for hearing protection, and ultimately improving workplace health and safety. Changing health behaviours associated with hearing loss prevention is a challenging task and requires health communication at all levels (intrapersonal, interpersonal, organisational, community and public/mass) to develop an effective intervention to prevent hearing loss among workers (Corcoran, 2007). The noise audit report and booklet in this study served as a method of health communication in conveying relevant information to the farmers that translated into preventive behaviour with respect to hearing loss.

The intervention study by Mctague *et al.* (2013) assessed the effectiveness of a daily noise exposure monitoring device, with visual cautioning alarms to alert workers when exposed to excessive noise. The workers also received a printed copy of monthly summaries of their exposure data individually, via mail. This study was part of a research collaboration initiative between the administrators of the company Alcoa Inc. and academic institutions (Yale University School of Medicine and Stanford University School of Medicine) as part of their hearing conservation programme. Volunteers were fitted with a device allowing them to monitor daily noise exposure under their hearing protection. Analysis included noise exposure levels of individuals who completed a minimum of six months of the intervention. The results highlighted that among volunteers downloading regularly, the percentage of daily exposures more than the OSHA action level (85 dB) decreased from 14% to 8%, while the percentage of daily exposures greater than 90 dB decreased from 4% to less than 2%. A further multivariate analysis was performed to determine if individual factors played a role in individual noise exposure reduction, and the results showed that neither age, gender, type of hearing protection device, baseline hearing nor baseline noise exposure level (average exposure level in first month of downloading) were significantly associated with the rate of decreased noise overexposures that individuals achieved. The initial results from this longitudinal study indicated that providing workers regular feedback on their daily noise exposure monitoring was feasible and effective in reducing noise exposures by raising awareness regarding noise exposure levels. Subsequently, this intervention promotes steps to control noise exposure by avoiding noise sources or limiting exposure time, informing supervisors of an excessive noise source and proper use of hearing protectors.

i. Body of evidence summary: Championed by leaders

The evidence from the quantitative literature identified for this review was consistent across the studies, supporting the importance of leadership, especially within an organisation with effective occupational NIHL prevention. However, the quality of evidence supporting the importance of leadership is low due to both studies having a cross-sectional and one group pre- and post-test design, as well as the high risk of bias identified. The effect of leadership in preventing NIHL was indicated by the reduction in noise exposure levels in the study by McTague *et al.* (2013) but the study by Williams *et al.* (2015) only reported qualitative feedback from the employees. The participants in the study by Williams *et al.* were conveniently sampled from the SFF programme that may have resulted in in sampling bias as the participants only included farmers who had previously received training on the proper use of hearing protectors, thus affecting the generalisability (external validity) across other job sectors. Hence, they were more aware of the dangers of excessive noise and more likely to take preventive measures, such as proper use of hearing protectors. Meanwhile participants in the other study were recruited from three manufacturing facilities of the company, which have different production processes (2 aluminium smelter and 1 turbine component) that resulted in different types of noise exposures between both component factories. The lack of blinding and randomisation, and no control group, may affect the internal validity of this study. Despite that, the results of the subjects' adherence did shed light on the challenges and possibilities of worksite interventions for health and safety. Although both studies were conducted in different job sectors, the populations studied were similar in terms of socioeconomic status, and the recommendations should be applied with caution. Figure 2 shows the summary of the body of evidence for the strategy championed by leaders.

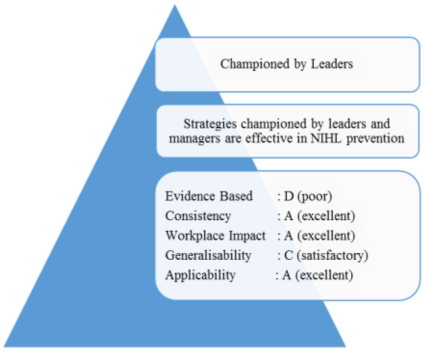

Figure 2. Body of evidence summary for championed by leaders

2. Strategy 2: One-off training

Two studies evaluated the effectiveness of a one-off training intervention in preventing NIHL, by increasing hearing protector use among employees exposed to excessive noise. McCullagh *et al.* emphasised the importance of hearing protection devices, whereas the study by Rocha *et al.* verified the effectiveness of an educational training programme in raising awareness on hearing protection among workers exposed to occupational noise. In both studies, the one-off training resulted in a substantial impact in raising awareness, as well as increased the use of hearing protectors among employees. These studies were performed in two very diverse job sectors, farming and healthcare services, but the sample population was not clearly defined in the latter study, especially in terms of job title and job description of the workers involved the study (McCullagh, 2011; Rocha *et al.*, 2011).

In the study by McCullagh, study participants received various types of hearing protection devices (foam plugs, semi-aural head band and ear muffs) via mail with user manuals, whereas Rocha *et al.* (2011) tested an educational training programme consisting of graphic material and illustrative figures with information on the importance of hearing, health effects of noise, NIHL prevention, workplace noise exposure level and proper use and care of hearing protectors, in addition to the level of sound attenuation the hearing protectors provide. The main outcome from the former study showed a significant overall increase of 44% in the self-reported use of hearing protectors (McCullagh, 2011). This suggested that the mail-based intervention, using hearing protectors, had a moderate to high impact on the workers and was clearly well accepted by the farm operators. This mailed intervention form of training, with instructions, made hearing protectors easily available to the workers, hence, it increases use and improved the workers' perceived self-efficacy with regards to safety and health. Unfortunately, factors influencing acceptance and usage of the hearing protectors are not completely understood. The health promotion model by Pender suggested that health promotion behaviour is influenced by attitudes, perceptions, practice, behaviour and individual factors (age and gender) (Pender NJ., 2011).

On the other hand, Rocha *et al.* (2011) reported up to a 13% improvement in mean accuracy per individual and 23% improvement in mean accuracy per question in the research group as compared to the control group after receiving the educational training. This significant increase reflected the improvement in knowledge regarding hearing, workplace noise levels, as well as the use and care of hearing protectors among participants whom received the educational training proving the effectiveness of this intervention since a fairly large impact was observed. These findings are supported by Hamblin in which training results in a chain reaction, which triggers learning to increase knowledge and awareness that leads to a change in behaviour and practice at the individual and organisational level (Hamblin, 1974). A similar flow was also proposed by Kirkpatrick's model of training evaluation criteria, which included four levels (reactions, learning, behaviour and results) that were positively intercorrelated (George and Elizabeth, 1989). According to Kirkpatrick, the four levels or categories served as measures of the effectiveness of training outcomes, where trainees' attitudes towards training gave rise to learning that resulted in the trainees applying new principles or techniques learnt. This would result in the organisation achieving desired goals, such as lowered cost for management, reduction of turnover and absenteeism of workers, as well as increase in production quality and quantity (George and Elizabeth, 1989). Training related to safety also served as a method for hazard communication between employers and employees and improved safety knowledge and performance, by raising awareness among workers exposed to noise hazards (Burke *et al.*, 2011).

In summary, the present study reinforces past research that training is impactful in changing individual as well as organisational attitudes and behaviours towards health and safety. Additionally, they also asserted the need for the use of educational training to improve the awareness of workers on the health effects of noise, the use and efficiency of protectors for hearing loss prevention, as well as care of such devices, to prevent NIHL. Periodic evaluations are also necessary to identify strengths and weaknesses of the training programme and its suitability for a given work environment.

i. Body of evidence summary: One off training

Although findings from both studies were consistent with other studies in which training was a frequently evaluated strategy in NIHL prevention, a high risk of bias must be cautioned since the level of evidence was weak, as only one study used a no-intervention control group for comparison. In both studies, the one-off training programme showed a very large impact among the workers with significant improvement in the main outcomes, such as safety knowledge and increased use of hearing protectors. Both studies reported the effectiveness of the intervention at different timelines, with McCullagh assessing immediate effects (within 1-hour post-training) and Rocha *et al.* describing medium-term effects (2-3 months post-training) (McCullagh, 2011; Rocha *et al.*, 2011). Although both studies showed significant improvement in safety knowledge and increased use of hearing protectors among workers post-training, the long-term effects of both training programmes were not studied. This may affect the internal validity of these outcome measures, particularly when compared with more objective outcome measures (e.g., observed hearing protector use and hearing protector attenuation). The study populations differed between both studies with Rocha *et al.* not clearly defining the job title or role of the participants, except that they were staff at a hospital (Rocha *et al.*, 2011). This is vital as hospital staff are made up of professionals and non-professionals that may affect the effectiveness of the training due to varying levels of education, hence, the findings from these studies must be applied with caution. Figure 3 shows the summary of the body of evidence for the strategy one-off training.

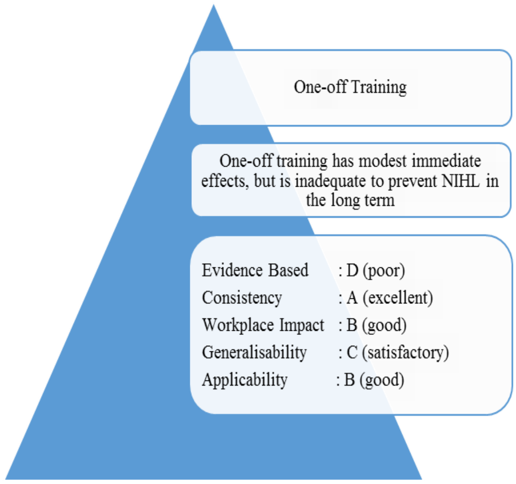

Figure 3. Body of evidence summary for one-off training

3. Strategy 3: Multifactorial intervention

Five studies evaluated the effectiveness of a combination of strategies in preventing NIHL. Only the study by Davies *et al.* evaluated the effectiveness of a hearing conservation programme. In this study, the outcome measured to determine the effectiveness of the hearing conservation programme was a standard threshold shift (STS) that showed a 51% reduction in the risk of STS to participants who were employed after the implementation of the hearing conservation programme (Davies, Marion and Teschke, 2008). The remaining four studies implemented a combination of different strategies to prevent NIHL but did not qualify as hearing conservation studies. All five studies were conducted in various job sectors including manufacturing, construction and food processing, as well as the education sector. The varying nature of the populations in the studies, especially the educational level, made it difficult to directly compare the interventions to determine their effectiveness. Takahashi *et al.* studied the effectiveness of an intervention that consisted of training and checklist-based, self-practice on the proper use of earplugs among university medical students. A significant improvement in sound attenuation of the students was reported, ranging from 7.7 dB to 11.7 dB in all frequencies (Takahashi *et al.*, 2011). In Seixas *et al.*, a comparison was made between a variety of combinations of interventions, primarily made up of three main strategies, baseline training, follow-up toolbox training and personal noise level indicators. The use of hearing protection devices significantly increased by 12.1% two months after the intervention and by 7.5% four months after the intervention, compared to pre-intervention use, with the greatest increase of up to 24% at two months and four months post-intervention observed in the group that received a combination of all three strategies (baseline training, follow-up toolbox training, and personal noise level indicators) (Seixas *et al.*, 2011). A similar pattern was observed in all the groups with an increase in the use of hearing protection devices two months post-intervention, but the mean use of hearing protection devices decreased at four months post-intervention in comparison to the former. Meanwhile, the study by Riga *et al.* examined screening protocols for workers exposed to excessive noise, while considering the duration of employment of the workers. The intervention included a noise exposure assessment, as well as a comparison of the effectiveness between a conventional audiometry and an Extended High Frequency (EHF) audiometry in the early detection of occupational NIHL. This study found that EHF audiometry, along with the noise exposure assessment, was effective in the early detection of NIHL, especially during the first decade of employment where the higher frequencies (12,500, 14,000 and 16,000 Hz) were affected during the first decade of employment (Riga *et al.*, 2010). However, the effect of EHF audiometry in workers more than 55 years of age were not studied and is important, as the retirement age in most countries is over 55 years old. Meanwhile, in the study by Rabinowitz *et al.*, an intervention combining daily noise exposure monitoring of workers and regular feedback on exposure levels showed a reduction of 0.5 dB/year in the average rate of hearing loss at a high frequency (2, 3 and 4 kHz) (Rabinowitz *et al.*, 2011). Although participants in the matched control group also showed a reduction in the average rate of hearing loss by 0.1 dB/year, it was fairly lower compared to the intervention group. A similar trend was observed during the comparison of the difference between the pre-intervention and post-intervention rates of hearing loss for both the intervention and the control groups, but the difference was not statistically significant (Rabinowitz *et al.*, 2011). This intervention is similar to the daily noise exposure monitoring device, with visual cautioning alarms, studied by McTague *et al.* However, in the study by Rabinowitz *et al.*, the additional component of risk communication via regular feedback from supervisors showed organisational commitment towards safety and health of workers and will further motivate them to practice safety culture at the workplace. Risk communication is important especially in enhancing knowledge, building employer-employee trust and credibility, as well as encouraging appropriate attitudes, behaviours and beliefs. Similar findings were observed among construction workers that were given daily on-site verbal communication on the safety level and the safety climate at the construction site (Kines *et al.*, 2010). However, another study by Michael *et al.* reported a minimal effect of risk communication between supervisors and subordinates in a wood manufacturing factory (Michael *et al.*, 2006). This difference could be explained by challenges involved in risk communication such as the literacy level, cultural values and language barriers, especially in places where the workforce primarily consists of migrant workers. Hence, it is important for an occupational health hazard communication standard to be established to ensure that its objective in promoting safety awareness and perception among workers is achieved. Two studies included a critical component of a Hearing Conservation Programme (HCP), which involved personal noise exposure monitoring and communicating exposure levels to the workers, but neither observed any significant findings (Rabinowitz *et al.*, 2011; Seixas *et al.*, 2011). This could be due to the small sample sizes of the study populations in both studies. Four studies used audiometry testing to measure outcomes. Three studies measured changes in the hearing threshold level, including the rate of hearing loss in both ears at high frequencies (2, 3 and 4 kHz), STS of 10 dB or greater at 2, 3 or 4 kHz in the better ear and extended high frequencies (9 to 18 kHz), while one study measured changes in sound attenuation performance with earplugs at both low and high frequencies (125 Hz–8000 Hz) (Davies, Marion and Teschke, 2008; Riga *et al.*, 2010; Rabinowitz *et al.*, 2011; Takahashi *et al.*, 2011). The varying methods used to measure hearing loss also made it challenging to make direct comparisons between the studies to determine the most effective strategy to prevent NIHL.

i. Body of evidence summary: Multifactorial intervention

There was a poor level of evidence supporting the effectiveness of a multifactorial intervention in preventing NIHL, mostly due to the lack of experimental study designs, such as randomised controlled trails, which would produce stronger evidence with less risk of bias. The elements of the hearing conservation programme by Davies *et al.* was not clearly defined and the magnitude effect of each element is unknown. The small sample size (10 medical university students) in the study by Takahashi *et al.* and high level of education of participants may result in a high risk of bias since participants may already have prior knowledge regarding the dangers of noise and preventive methods to preserve hearing (Takahashi *et al.*, 2011). Four studies the lacked a proper control group as audiometric tests were generally performed only for noise exposed workers at risk of hearing loss (Riga *et al.*, 2010; Rabinowitz *et al.*, 2011; Takahashi *et al.*, 2011; McTague *et al.*, 2013). However, the results from all five studies were consistent with findings across the available scientific literature. Verbeek *et al.* and Laird *et al.* both concluded that interventions that combine multiple strategies are effective in NIHL prevention (Laird *et al.*, 2012; Verbeek *et al.*, 2015). The studied populations varied across all five studies, with a wide range of demographic characteristics, but the interventions showed moderate to large impacts, especially in terms of improvement in sound attenuation of the hearing protection devices, audiometric hearing threshold changes and reduced noise exposure level. Nonetheless, these results need to be applied to the target population and generalised with caution, as the longest follow-up period (18 years) was found in the studies by Davies *et al.*, while the remaining studies focused more on short-term or immediate effects post-intervention (ranging from 7 days to 4 years). Figure 4 shows the summary of the body of evidence for the strategy multifactorial intervention.

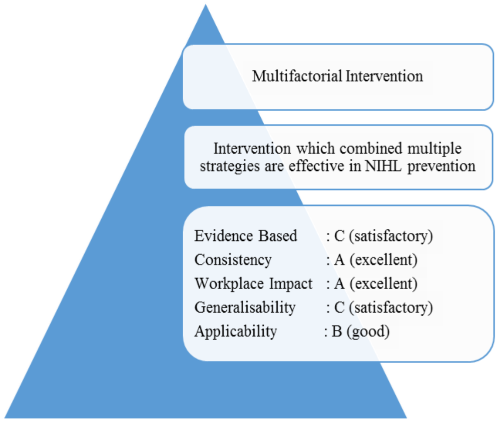

Figure 4. Body of evidence summary for multifactorial interventions

This review provides a high level of evidence and summary of systematically derived information on strategies to prevent NIHL for future development of effective hearing conservation programs and policy making. However, direct comparison of effectiveness between interventions is difficult due to the different study designs and outcomes measured.

V. CONCLUSION

This systematic review identified championed by leaders, one-off training and an intervention that combines multiple strategies (multifactorial intervention) as three key strategies effective in the prevention of NIHL among noise-exposed workers. All three key strategies showed positive outcomes with moderate to large impacts, but a comprehensive, multifactorial intervention that combines multiple strategies, such as an HCP, is proposed as the method of choice in prevention of NIHL. For an intervention to be effective, it requires good organisational support or leadership, especially in creating a safety climate at the workplace. One-off training showed modest, immediate effects but lacked evidence on the frequency or intervals for training to be delivered to the workers. Although the quality of evidence is poor overall, there is positive consistency within the literature available, and the results can be generalised to the population of interest, with caution, as the effects on different occupations are still lacking. Further research is needed to understand the long-term effects of these interventions, especially since NIHL develops gradually over a long period of time.

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