What do workers know and practise?

Occupational noise exposure and noise-induced hearing loss among Tanzanian iron and steel workers

Israel Paul Nyarubeli

Thesis for the degree of Philosophiae Doctor (PhD)
University of Bergen, Norway
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Scientific Environment

This project was implemented in a scientific community at the University of Bergen, Centre for International Health; the Research group for Occupational and Environmental Medicine – Haukeland University Hospital, Bergen Norway; the Muhimbili University of Health and Allied Sciences (MUHAS), Tanzania; and the Occupational Safety and Health Authority (OSHA) under the Ministry of Labour in Tanzania. The project was also associated with the larger project named “Reduction of burden of injuries and diseases due to occupational exposures through capacity building in low income countries” funded by NORHED and implemented by the University of Bergen, the Muhimbili University of Health and Allied Sciences, in Tanzania and the Addis Ababa University in Ethiopia, thereby forming a strong supporting scientific environment for its accomplishments.

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Knowledge is powerful if acquired at an appropriate time, but information is only powerful if delivered at the right time to the right people!

Israel P. Nyarubeli

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Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ACOEM	The American College of Occupational and Environmental Medicine
AMA	American Medical Association
ANOVA	Analysis of variance
CI	Confidence Interval
dB	Decibel
HPDs	Hearing Protective Devices
HTL	Hearing Threshold Level
Hz	Hertz
ISO	International Organization for Standardization
KAP	Knowledge, Attitude and Practice
LMICs	Low- and Middle-Income Countries
MUHAS	Muhimbili University of Health and Allied Sciences
NDC	National Development Corporation
NIHL	Noise-Induced Hearing Loss
NIPTS	Noise-Induced Permanent Threshold Shift
NIOSH-US	National Institute for Occupational Safety and Health- United States
OSHA	Occupational Safety and Health Authority
PTA	Pure Tone Audiometry
REK	Regional Committees for Medical and Health Research Ethics
SLM	Sound Level Meter
SNHL	Sensorineural Hearing Loss
SPSS	Statistical Package for Social Sciences
TTS	Temporary Threshold Shift
TWA	Time Weighted Average
US	United States
WHO	World Health Organization

Abstract

Background: Employees work to earn a living. Noise-induced hearing loss (NIHL) due to occupational noise is an underrated public health problem that has been increasing during the past two decades, mostly in low-income countries. Iron and steel factories are among the workplaces that have high levels of noise exposure, and because of heavy industrial investments, a significant number of people are employed in these factories. However, little is known about the status of occupational noise exposure and prevalence of NIHL. In addition, we have no information on workers' knowledge, attitude and practices in terms of occupational noise, NIHL and the use of hearing protection devices (HPDs).

Objectives: We aimed at gaining knowledge about occupational noise exposure levels and NIHL among iron and steel workers in Tanzania. We also wanted to assess the level of knowledge, attitude and practice (KAP) regarding noise exposure, NIHL and the use of hearing protection devices.

Material and methods: We randomly selected 253 male production line workers from four randomly selected iron and steel factories in Tanzania. All the selected workers participated in a KAP study, 163 participated in an exposure study, and 221 workers in prevalence of NIHL study together with external control group of 107 workers. We did a Walk-through survey (with checklist) and assessed both personal and area noise exposure respectively using personal noise dosimeter (Brüel and Kjaer type 4448) and sound level meter (Brüel and Kjaer type 2250). We assessed NIHL by Pure Tone Audiometry (PTA) using Interacoustics AD 226. In addition, we used an interview questionnaire to conduct a KAP study and to acquire information about basic sociodemographic characteristics.

Results: Workers were exposed to an average personal noise exposure ($L_{\mathrm{EX,8h}}$) of 92.0 dB (A) (n=326). Workers did not use HPDs. About 90% of all measurements were above the OEL of 85 dB(A).

The average area noise level was 90.5 dB(A). The personal noise exposure was significantly higher (2.6 dB (A); 95 CI = 2.1- 3.1) compared to the corresponding area measurements. A total of six determinants for noise exposure (three in each section) were identified. These were; - the furnace installation, billet weighing/transfer and manual handing or raw materials/ billets/crowbars for furnace section and the size of cutting machine, the steel billet weight and feeding re heating furnace in the rolling mill section. The overall prevalence of hearing loss was significantly higher among exposed workers (48%) than among the controls (31%). The mean scores for attitude and practice related to occupational noise, NIHL and the use of hearing protection devices (HPDs) differed significantly between the four factories (one-way ANOVA, $p<0.001$) while mean knowledge scores did not differ between any of the four factories. In addition, the majority of workers had poor knowledge and practice but had a positive attitude.

Conclusions: The workers in Tanzania's iron and steel factories were exposed to high noise levels above the occupational exposure limit of 85dB(A) and they did not use HPDs. The prevalence of NIHL was higher than among the controls. The workers had poor knowledge regarding noise exposure and related NIHL. Implementation of noise control measures such as provision of HPDs and establishment of a hearing conservation programme (HCP) is recommended.

Ikisiri

Utangulizi: *Watu hufanya kazi ili wapate riziki. Tatizo la Uziwi utokanao na kelele mahali pa kazi limekuwa halipewi kipaumbele na limethibitika kuongezeka kwa miongo miwili iliyopita, hasa miongoni mwa nchi zinazoendelea. Mazingira ya kazi katika viwanda vya nondo na chuma ni miongoni mwa maeneo yanayoainishwa kuwa na viwango vikubwa vya kelele. Viwanda hivi vimeajiri watu wengi kutokana na wingi na ukubwa wake. Kwa bahati mbaya hakuna ufahamu wa kutosha kuhusu viwango vya kelele na uwepo wa uziwi miongoni mwa wafanyakazi wa viwanda hivi. Isitoshe, hakuna taarifa sahihi juu ya kiwango cha uelewa wa wafanyakazi juu ya kiwango cha makelele na athali zake kwa usikivu, mitazamo na vitendo vyao juu ya matumizi ya vifaa vya kujikinga na na kelele wawapo kazini.*

Malengo: *Kuongeza elimu na ufahamu juu ya viwango vya kelele pamoja na athari kwa usikivu (uziwi) miongoni mwa wafanyakazi wa viwanda vya nondo na chuma nchini Tanzania. Pia, kutathmini kiwango cha uelewa wa wafanyakazi juu ya kiwango cha makelele na athali zake kwa usikivu, mitazamo na vitendo vyao juu ya matumizi ya vifaa vya kujikinga na kelele wawapo kazini.*

Mbinu na vifaa vya utafiti: *Utafiti huu ulishirikisha sampuli ya wafanyakazi 253 kutoka miongoni mwa wafanyakazi wa kiume waliokuwa kwenye mitambo ya uzalishaji wa nondo viwandani nchini Tanzania. Wafanyakazi wote 253 waliochaguliwa walishiriki katika tathmini ya kiwango cha uelewa wa wafanyakazi juu ya kelele mahali pa kazi na athali zake kwa usikivu, wafanyakazi 163 walishiriki katika upimaji ili kutambua viwango vya kelele katika mazingira ya kazi ndani ya viwanda wafanyakazi 221 walishiriki katika upimaji kiwango cha tatizo la uziwi miongoni mwa wafanyakazi wa viwandani sambamba na kundi linganifu la waalimu 107 kutoka shule za msingi za umma. Vifaa maalumu vilitumika katika upimaji wa kelele kwa wafanyakazi (personal noise dosimeter) pamoja na maeneo wafanyiayo kazi (sound level meter). Vilevile njia na kifaa maalumu (audiometer) kilitumika kupima kiwango cha usikivu kwa wafanyakazi wote walioshiriki. Pia, mbinu ya hojaji kwa kutumia dodoso ilitumika katika kupima kiwango cha uelewa miongoni mwa wafanyakazi wafanyakazi juu ya kiwango cha makelele na athali zake kwa usikivu,* *mitazamo na vitendo vyao juu ya matumizi ya vifaa vya kujikinga na na kelele wawapo kazini.*

Matokeo: *Wastani wa kiwango cha kelele kwa wafanyakazi-kilichopimwa kwa mfanyakazi mmoja mmoja ($L_{EX,8h}$) kilikuwa desibeli 92 (n=326). Wafanyakazi hawakutumia vifaa vya kujikinga na kelele masikioni. Kiasi cha 90% ya vipimo vyote vya viwango vya kelele vilikuwa juu zaidi ya kiwango salama cha kelele mahali pa kazi ambacho ni desibeli 85.*

Wastani wa kiwango cha kelele-kilichopimwa kwa maeneo ya kufanyia kazi kilikuwa desibeli 90.5. Wastani wa kiwango cha kelele kilichopimwa kwa mfanyakazi mmoja mmoja kilikuwa kikubwa kulinganisha na kile kilichopimwa maeneo ya kazi (desibeli 2.6; 95 CI = 2.1- 3.1). Visababishi sita vya mabadiliko ya kelele (kupanda au kushuka) viliainishwa kutoka idara zote mbili. Katika idara ya tanuru, visababishi vilikuwa; - mahali tanuru lijengwapo (juu ya sakafu au chini ya ardhi), namna ya upimaji wa bileti za chuma na namna ya ubebaji na utumiaji wa vifaa. Kwenye idaya ya vinu vya kutengeneza nondo, visababishi vilikuwa ukubwa wa mashine ya kukatia nondo, jinsi ya ulishaji wa tanuru la uyeyushaji wa bileti za chuma na uzito wa bileti za chuma.

Kiwango cha uziwi (hearing loss) kilikuwa kikubwa miongozi mwa wafanyakazi wa viwandani (48%) zaidi ya kundi linganifu la waalimu (31%). Wastani wa matokeo ya Mtizamo na Vitendo miongoni mwa wafanyakazi yalitofautiana baina ya wafanyakazi wa kiwanda kimoja na kingine, wakati wastani wa kiwango cha uelewa hakikutofautiana niongoni mwa wafanyakazi wa viwanda vyote. Vilevile, wafanyakazi walio wengi walikuwa na uelewa hafifu juu ya athari za kufanya kazi katika mazingira yenye kelele kubwa.

Muhtasari na hitimisho: *Wafanyakazi katika viwanda vya nondo na chuma Tanzania waligundulika kufanya kazi katika mazingira yenye kelele kubwa zaidi ya kiwango salama cha kelele mahali pa kazi ambacho ni desibeli 85 na hawakutumia vifaa stahiki vya kujikinga. Kiwango cha uziwi kilikuwa kikubwa miongoni mwa fanyakazi wa viwandani kuliko kundi linganifu. Wafanyakazi walio wengi walikuwa na uelewa hafifu juu ya athari zitokanazo na kufanya kazi katika mazingira yenye kelele kubwa.*

Hivyo basi, tunapendekeza uwepo wa uthibiti wa kiwango cha kelele viwandani ikijumuisha matumizi ya vifaa kinga pamoja na uanzishaji wa programu endelevu ya uhifadhi wa usikivu mahali pa kazi.

List of publications

The intellectual content of this thesis is built on the following papers

Paper I

Nyarubeli, I.P.; Tungu, A.M.; Bråtveit, M.; Sunde, E.; Kayumba, A.V.; Moen, B.E. Variability and Determinants of Occupational Noise Exposure Among Iron and Steel Factory Workers in Tanzania. Ann Work Expo Health 2018;62(9): 1109-1122.doi:10.1093/annweh/wxy071.

Paper II

Nyarubeli, I.P.; Tungu, A.M.; Moen, B.E; Bråtveit, M. Prevalence of Noise-Induced Hearing Loss among Tanzanian iron and steel workers: A Cross-Sectional Study. Int. J. Environ. Res. Public Health 2019, 16, 1367; doi:10.3390/ijerph16081367.

Paper III

Nyarubeli, I.P.; Tungu, A.M.; Bråtveit, M; Moen, B.E. Occupational noise exposure and hearing loss: A study of Knowledge, Attitude and Practice among Tanzanian iron and steel workers. Arch Env Occup Health 2019. doi:10.1080/19338244.2019.1607816

Contents

ANNEXES

Definition of terms

Audiogram: a presentation, in graphical or tabular form, of the hearing threshold levels of the ears of the test subject, determined under specified conditions and by a specified method, as a function of frequency, i.e. a picture of how a person hears at a given place and time under given conditions.

Decibel: In Acoustics, it is a unit used to measure the intensity of a sound or the sound power level of an electrical signal by comparing it with a given level (reference quantity) on a logarithmic scale. It is used to measure sound intensity.

dBHL: decibels hearing level, a logarithmic measurement of human hearing that, through standardization, has defined 0 dBHL as the faintest sound that the average normal-hearing person can detect.

Hearing loss: deviation or change for the worse from what is normal on the threshold of hearing.

Hearing threshold: Is the sound level below which a person's ear is unable to detect any sound. For adults, 0 dB is the reference level

Noise: is unwanted sound. In this thesis, we use the term occupational noise for unwanted sound in the workplace.

Noise-induced hearing loss (NIHL)in this thesis: Hearing Threshold Level ≥ 25 dB hearing level in either ear at 3, 4 or 6 kHz.

1.0 Introduction

This thesis is about occupational noise exposure and noise-induced hearing loss (NIHL) among iron and steel workers in Tanzania. Employment in iron and steel factories has been a blessing to a significant number of people in Tanzania, but the presence of workplace hazards such as occupational noise might be a problem. High noise levels associated with the increased risk of NIHL is an underestimated global public health concern [4]. It is estimated that 466 million people live with disabling hearing loss (above 40 dB) globally, one-third of which is attributed, at least in part, to noise exposure [5, 6]. The prevalence of NIHL is estimated to be higher in lower and middle-income countries (LMICs) including Tanzania, than other parts of the world [7]. However, there is inadequate information about the existing situation in factories in Tanzania and no accessed research in this country or the neighbouring countries specifically addresses the noise exposure levels and prevalence of NIHL. This information is necessary for planning and implementing workplace NIHL preventive interventions. Hence, this study was important.

The synopsis is built on three papers published in peer reviewed international journals and presents the knowledge gained in the area of occupational noise and NIHL. This information can be shared and used in intervention programmes by workers, management-level personnel, governing institutions, global academia and stakeholders for similar workplaces with the same characteristics. We have systematically presented the general understanding of noise and hearing loss and have narrowed the focus to occupational noise exposure and NIHL which is central to our methodology, results and discussion. Finally, we draw conclusions and present recommendations for improvement and further research.

1.1 Noise and hearing loss

The World Health Organization (WHO) and International Labour Organization (ILO) define noise as unwanted sound [8, 9]. Sound is the result of pressure variations, or oscillations, in an elastic medium (e.g., air, water, solids), generated by a vibrating surface, or turbulent fluid flow [9]. Sound is characterized by frequency, i.e. the number of pressure variation cycles per second, in Hertz (Hz); wavelength, i.e. the distance travelled by the pressure wave during one cycle; and the period, i.e. the time taken for one cycle of a wave to pass a fixed point. Usually, sound level is measured in decibel (dB), i.e. the logarithm of the ratio of two sound intensities or two sound pressures [10]. Sound waves are detected in human ear, starting with vibrations of the eardrum. In addition, the human ear has different sensitivities to different frequencies, i.e. less sensitive to extreme high and low frequencies [9]. The human ear has a remarkable dynamic range of roughly 0-120 dB (10^6 sound pressure level), which allows for detection of sound from the faintest noise to painful stimulation [11]. At a given sound pressure level, a healthy human cochlea can detect and encode sound waves across frequencies ranges from 20Hz to 20kHz [9, 11].

When sound waves are received by the external ear, the waves move in the external ear canal and may vibrate the ear drum (tympanic membrane), connected to three bones (malleus, incus and stapes). The vibration causes movement of the fluid within the inner ear cochlea. Thus, the cells in the inner ear transduces vibration into nervous impulses while producing a frequency and intensity analysis of the sound. The latter is then transmitted to the brain where the details of the sound are analysed. However, the sound or noise-sensitive components of sound within the ear are the outer hair cells in the basilar part of the cochlea. This is the most sensitive, in part because of the harmonic amplification of the ear canal and in part because of absolute sensitivity [12]. This part responds to 4kHz and adjacent frequencies of 3kHz and 6kHz. It is worth noting that once these hair cells degenerate for any reason, including being exposed to excessive noise for a long period of time, they do not recover, and permanent hearing loss eventually develops with an increase in hearing threshold [12, 13]. When assessing impact on humans, noise is normally classified as occupational noise, i.e. noise in the workplace (industries, mining, agriculture, military, constructions etc.), or as environmental noise, which includes noise in all other places at domestic, community or residential level such as leisure, traffic, music noise [14]. For brevity, we use the term noise throughout this thesis to mean occupational noise.

1.2 Occupational noise exposure

In this study, occupational noise denotes unwanted sound level in the workplace that has a potential to cause hearing damage [15]. Exposure of human ears to high intensity sound level above 85 dB(A) for 8 hours a day over time is associated with an increased risk of damage to hearing [16]. Occupational noise is of paramount importance because the associated hearing loss is in principle preventable. Studies have reported that workers in the military, mining, construction, agriculture, and manufacturing industries, including iron and steel factories, work in high noise levels emitted from operating machines, tools, equipment and from various tasks and activities performed [17-21]. It was estimated that more than 15% of industrial workers were exposed to a noise level above 85 dB(A) in 1990s in industrialized countries, including Germany. In the United States (USA) alone, the figure was over 22 million (17%) of employees [17, 22, 23]. In recent years, the world has witnessed an industrial shift from the developed part of the world to the developing countries including sub-Saharan Africa [24-26]. Unfortunately, there is lack of reliable data, and empirical studies on noise levels for many manufacturing industries including iron and steel are still scarce. Governments in these countries need to be aware of this; hence, protection of workers from high noise levels at work should be an integral part of public health interventions.

Worker's exposure to detrimental noise in the workplace depends on several factors. During production processes, noise generation is an inherent trait of operating machines, equipment and tools used, and of the way different tasks are performed by individual workers. In addition, the design of the workplace influences the occupational noise level and may include sound absorbing materials in the building structure as well as whether the machinery and processes are enclosed or have sound barriers [17].

1.3 Assessment of occupational noise exposure

Noise assessment is typically done to establish and document the levels at which the noise is hazardous to the human ear. Identification of work locations and tasks with harmful noise exposure and workers who may be at increased risk of hearing loss [27] is an important part in establishment of workplace hearing conservation programme with effective noise control measures. To achieve this, prior to noise measurement in the workplace, a Walk-through survey is recommended as an important part of noise hazard identification (in the risk assessment process) to collect information necessary to describe the working environment and identify determinants for noise exposure, which is also a basic prerequisite for planning how sampling is to be conducted [28]. Such information includes noise sources, workplace layout, types of machines and production processes, number of workers per section with their shift patterns, production capacity, working durations, changes in production processes or machinery (if any). In addition, information is normally collected on the availability of health and safety policies, the use of hearing protection devices and the perceived noise levels on the site.

The two common devices for noise exposure assessment at workplaces are integrating- averaging sound level meter (SLM) and personal sound exposure meters (dosimeters) [29]. SLM is a hand- held device that is normally used to measure static or stationary sound pressure level (from noise emitting substances such as machines or equipment or tasks) over a period (referred to as area measurement or survey). Also, it is used for noise measurement at ear level (10–20 cm from human ear). This device is relatively cheap, easy to use and has the advantage that a single device can be used to gather details about the source of noise in the workplace for noise mapping. The personal noise dosimeter, on other hand, is a specific device for measurement of personal noise exposure. The device is portable and is fitted to the worker's shoulder (10 -15 cm from the most exposed ear) for the full-shift noise measurement and provides a noise profile of the working shift taking various variabilities in working conditions, tasks and activities into consideration. However, the current personal dosimeters cannot measure noise level above 140dB. In addition, measured values maybe confounded by worker's behaviour (accidental or deliberate) such as touching the microphone, whistling, blowing or shouting into the microphone, or even removing and replacing it before the noise accessor is due to collect it[30].These two devices (the SLM and the personal noise dosimeter) have been widely used in different noise exposure studies[30-32].

The International Organization for Standardization (ISO standard) 9612:2009 provides an appropriate engineering method for measuring and calculating noise exposure level at workplace. Estimates obtained through this method may provide useful information for planning and implementing noise control measures. The two devices, i.e. integrating-SLM and personal noise dosimeters are recommended in this ISO standard for conducting workplace noise exposure assessment [29].

1.4 Effects of occupational noise exposure

Workers' ears exposed to excessive continuous or impulsive sound levels above 85dB(A) are likely to have their hearing threshold increased [7, 13, 21]. The increase in threshold of hearing due to noise exposure is commonly referred to as noise-induced hearing loss (NIHL) or sometimes sensorineural hearing loss because it affects the inner part of the ear [13, 33]. This is why, the audiogram of an ear that has been exposed to high noise shows a dip or notch at frequencies of 3-6kHz (figure 1) [12]. The risk of NIHL is related to the duration and intensity of occupational noise exposure, as well as individual susceptibility to noise trauma [11].

In general, occupational noise exposure may result in both auditory health effects such as NIHL (an irreversible loss of auditory sensory cells in the cochlea) and tinnitus (change in sound perception, for example ringing in the ear that cannot be attributed to the external source) as well as non-auditory health effects such as speech intelligibility, cognitive performance, decreased self-esteem, social isolation, annoyance and sleep disturbance. Occupational noise may cause daytime sleepiness, decreased attention to tasks (which in turn can cause accidents and injuries at work), increased workers' compensation costs and expenses for hearing aids, in addition to an increased risk of cardiovascular diseases [14, 34, 35]. In this study, we focused on NIHL as a primary outcome due to occupational noise exposure.

The different definition or metrics of NIHL makes comparisons among studies problematic (Table 1) [4, 36]. Some definitions are based on a hearing threshold shift from the baseline audiogram such as that of the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) from the United States of America (Table 1). Other regulatory bodies use the 'noise notch' definition (a dip at 3, 4 or 6kHz with recovery at 8kHz) (figure 1), while others use the average threshold level estimates for one (worse or better) or both ears at selected frequencies with a cut-off value of 25 dB HL [4, 37-40]. In addition, there may be other definitions and explanations applied based on other methods such as tympanometry, OAE and self-report. However, there is a common understanding that low frequencies (0.5 – 2kHz) are used for assessing speech comprehension and the higher frequencies (3, 4 and or 6kHz) are primarily associated with noise exposure [40, 41]. For this reason, the NIHL definition based on the higher frequencies from the Norwegian Labour Authority and corresponding to the recent WHO definition and The American College of Occupational and Environmental Medicine (ACOEM) (at 3, 4 or 6 kHz) was used in our study because no such guidance exists in Tanzania (Table 1).

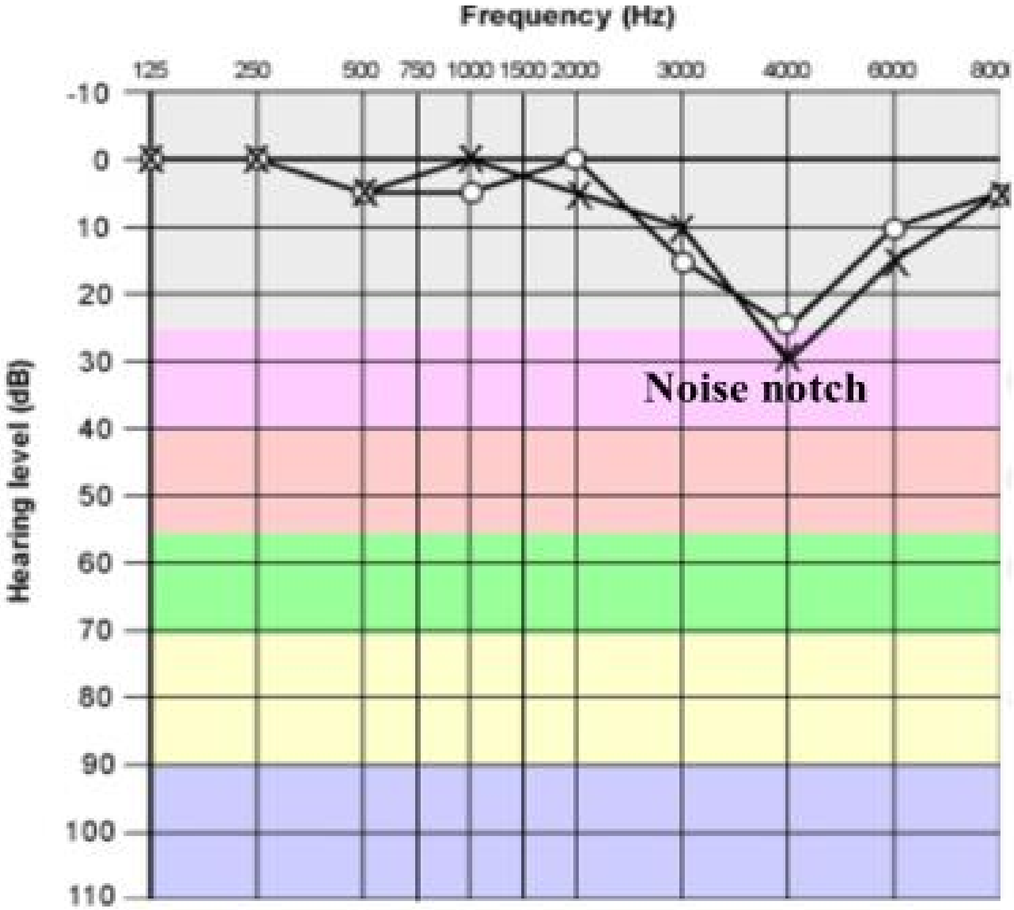

Figure 1. An example of audiogram of a person exposed to excessive noise [X = left ear; O = right ear] [3]

Table 1: Definition of NIHL from selected regulatory institutions

Institution (ref)	NIHL definition/metric
WHO [42]	Permanent decrement in hearing threshold levels (HTLs), with a characteristic reduction of hearing sensitivity at frequencies of 3, 4 and/or 6 kHz, and relatively better hearing sensitivity in surrounding frequencies (i.e. 2 or 8 kHz)
NIOSH- US (as STS) [23]	An increase in the HTL of 15dB or more at any frequency (0.5, 1, 2, 3, 4 or 6 kHz) in either ear, that is confirmed for the same ear and frequency by a second test within 30 days after the first test.
American Medical Association (AMA) - hearing impairment [4]	Hearing threshold average at 0.5, 1, 2, and 3 kHz >25dB HL, with 1.5% monaural impairment for each decibel greater than 25.
OSHA-US (STS)[4]	A 10-dB change from the baseline audiogram in the average of HTLs at 2, 3 and 4 kHz, with age correction allowed Or A 10-dB change from the baseline audiogram in the average of HTLs at 2, 3 and 4 kHz ≥ 25dB HL.
Norwegian Labour Authority [43]	HTL ≥ 25 dB hearing level in either ear at 3, 4 or 6 kHz
Health and Safety Executive -UK (hearing impairment) [44]	Sum of HTLs at 1, 2, 3, 4 and 6 kHz. Compare value with figure given for appropriate age band and gender in a standardized table.
ACOEM [40]	Hearing loss (sensorineural) that is a function of continuous or intermittent noise exposure, intensity and duration, and which usually develops slowly over several years, characterized by a dip sign of the audiogram at the high frequencies of 3, 4 and 6 kHz recovering at 8 kHz

1.5 The magnitude of NIHL

Hearing loss is an underestimated public health concern [4, 45]. The global magnitude of disabling hearing loss (above 40 dB) from all causes has increased during the past two decades from 120 to 466 million people in the period 1995–2018 and the figures are expected to increase in the future [5, 7]. Apart from occupational noise exposure, hearing loss may also be caused by a number of risk factors such as increasing age [46-48], smoking [49], exposure to organic solvents, [50] the use of ototoxic medicines, [49, 50] vibration, genetics, congenital factors (maternal rubella, syphilis, low birth weight, birth asphyxia), blunt head or ear injury and or surgery, ear infections, illnesses (meningitis, measles, mumps, otitis media) [11, 49, 51, 52]. However, in workplaces, noise exposure contributes significantly to the increased prevalence of hearing loss [53]. Estimates of the prevalence of hearing loss related to noise exposure, i.e. NIHL above 85dB(A) vary in the range of 7–21% or higher [49]. Approximately 5% of world population suffers from occupational or recreational NIHL at great economic cost and detriment to the quality of life of affected individuals [52]. Prevalence is estimated to be higher in the low and middle-income countries compared to the findings in other parts of the world [49]. In Tanzania for example, the prevalence of NIHL in studies in the field of mining was 47% [54]. This may be due to ongoing economic investments in industrialization coupled with challenges related to an inadequate public health policy, lack of regulatory frameworks and limited resources [55]. In addition, the coverage of occupational health services and hence awareness in the working population has been low [56].

1.6 Evaluation of NIHL

NIHL can be screened or diagnosed in several ways. The most commonly used method and technique is Pure tone Audiometry (PTA). Other methods include tympanometry, and Otoacoustic emission (OAE) [57-59]. Some simple tests for hearing loss include the Whispered voice test, which has been used in primary care when access to an audiometer is problematic; the Tuning fork test, such as Rinne and Weber tests [11, 60]; also, Self-report and a Rubbing sound from examiner's fingers [61] have been used.

Tympanometry measures acoustic impedance (resistance of acoustic energy flowing from the ossicular chain to inner ear) and admittance (how easily the acoustic energy flows) in the middle ear [57, 58]. It is a clinical diagnostic method used to measure the physical properties of the middle ear system. It has been widely used in the evaluation of middle ear functioning during routine examination as it is cheap, quick and non-invasive [57]. However, it is not effective on infants [62].

Otoacoustic emission (OAE) is an acoustic energy generated by outer hair cell receptor that disappears when the inner ear has been damaged [63]. OAEs are caused by the motion of the cochlea's sensory hair cells as they are responding to auditory stimulus and can be recorded by a microphone fitted into the ear canal [64]. The presence of OAE means that the middle ear and cochlea respond normally to sound stimulation. This makes easier to access the sensitivity of efferent auditory system after exposure to high noise levels or ototoxic medicines [65]. This method is said to be effective and reliable for identifying hearing defects in infants and children under the age of three, but with infants, it is usually not easy to conduct [65]. For NIHL diagnosis, this method still needs more investigation [34].

Pure Tone Audiometry (PTA) or simply Audiometry is an ear screening procedure that can detect small changes in either ear in the hearing threshold of an individual. This method is most frequently used to examine the hearing ability of adults. Results are presented as an audiogram expressed as a graph of hearing threshold level based on a function of frequency and time under given conditions [23]. This makes it easier to identify individuals at work who are at risk of developing hearing loss due to exposure to high noise levels and to determine possible preventive measures. An electronic set of devices called audiometer is the commonly referred diagnostic device, i.e. pure tone air conduction audiometer. It has proved to be highly sensitive (94%) and specific (70-80%) in detection of SNHL [66]. The test is conducted after otoscopic examination of the ear with an objective of examination of gross abnormalities such as impacted ear wax, pus, blood or any other occlusion. During audiometry, the background noise had to be controlled, with the test preferably conducted in a booth [67]. Despite this limitation, PTA is still the gold standard tool for hearing screening and/or evaluation in adults [68, 69].

For valid audiometric results, ISO 8253-1:2010 [Acoustics-Audiometric test methods Part1: Pure-tone air and borne conduction audiometry] specifies procedure and requirements for PTA. It provides, in addition, conditions for the audiometric test environment and the maximum values for the sound pressure levels. For example, the maximum permissible ambient sound pressure levels in one-third octave bands, $L_{s,max}$ (in dB) for PTA to be conducted with the test frequency range 0.25-8kHz, are 66dB for 31.5Hz and 33dB for 8kHz respectively [70]. Furthermore, the audiometer should comply with the International Electrotechnical Commission (IEC) standard [IEC 606450-1:2012, Part 1; Electroacoustics- Audiometric equipment: Equipment for pure-tone audiometry]. The ISO 1999 provides a model for the prediction and distribution of risk of noise-induced permanent threshold shift (NIPTS) synonyms to Permanent NIHL at a given frequency, in a population of a given age, after an exposure to a certain continuous equivalent noise level (steady state) [71]. However, the estimates may be compromised by noise characteristics in different workplaces, for example in iron and steel factories, where a mix of noise characteristics are common. Also, this standard uses a reference population mainly from the USA, which differs (in socio-demographic characteristics) from other countries and regions, including Tanzania, where normative data on hearing loss in the community and other working population does not exist.

1.7 Occupational exposure limits (OEL)

The range of audible frequencies of the human ear is between 20 Hz to 20 kHz [72]. The effects caused by noise on human hearing have prompted actions geared to safeguard normal hearing ability. It is estimated that the risk of hearing loss due to exposure to an average A-weighted equivalent sound level of 80dB(A), 85dB(A) and 90dB(A) and above is negligible, marginal and material respectively [73]. Nevertheless, there might still be individuals acquiring NIHL due to variation in the susceptibility of the ear to the effect of noise. Therefore, different country/regional

and or professional institutions set safe noise limits, i.e. OEL to prevent the majority of the population from developing NIHL. The OEL is used as a guide for planning and establishment of a hearing conservation programme and for monitoring occupational noise exposure among workers (as a compliance tool). It is worth noting that selection and or setting of occupational noise exposure limits (which is done by regulatory bodies) takes into consideration ethical, economic, social and political factors not amenable to international standardization, resulting in differing OEL values set by different responsible bodies or entities [71]. In addition, the administration of the set OEL values varies in different countries and regions of the World. In the USA, for example, the NIOSH, a professional body, has set the Recommended Exposure Limit (REL) at 85 dB(A) TWA with a peak of 140dB(A) aiming at reducing excess risk of material impairment of 8% of noise exposed population over working lifetime (normally 40 years) [23]. The American Conference of Governmental Industrial Hygienists (ACGIH) have a Threshold Limit Value (TLV) of 85 dB(A) with a peak of 140dBC using a 3 dB exchange rate [74]. This noise exposure limit is used by many countries in the world, including Tanzania [42]. The European Union (EU) sets lower and upper exposure action values of 80 dB(A) and 85dB(A) respectively, with the exposure limit at 87dB(A) with a peak noise level of 135 dB(C); the United Kingdom uses the same value [75, 76]. On the other hand, the USA Occupational Safety and Health Administration (OSHA) – a regulatory body, has set a permissible exposure limit (PEL) at 90 dB(A) TWA with a 5dB exchange rate aiming at reducing excess risk of material impairment for 25% of the noise-exposed population over their working lifetime [23]. This is also used in some other countries, such as India [77].
In Tanzania, OEL for noise was recently set by the Tanzania Bureau of Standards (TBS), a government agency that is responsible for formulation of all national standards. OSHA- Tanzania (a regulatory body) on the other side, administers the OEL. Currently, there is no independent professional institution responsible for occupational safety and health that provides technical guidelines, and this is the case in many developing countries.

1.8 Noise control in the workplace

Controlling noise in the workplace may be challenging due to inherent characteristics of industrial machines, equipment and tools used in production processes. Consideration of some other potential factors such as cost, effectiveness, technical feasibility and sociocultural aspects are necessary when planning for and selecting noise control measures [14]. There are potential noise control measures technically arranged in hierarchical order. These measures are grouped under general categories such as elimination, substitution, administrative and the use of hearing protective devices, which is regarded as the last option [23, 78]. However, the effectiveness of the noise control measures in workplaces largely depends on actions taken to control the underlying noise determinants, i.e. those factory and worker-related factors that potentially influence the occupational noise [79]. Usually, a combination of control measures yields maximum output [79].

Elimination measures are aimed at eradicating the noise at the source or reducing it to a level that no longer puts the human ear at risk [44]. These may include direct actions to diminish noise at the source, such as elimination of impact between metal surfaces or avoiding the use of noisy machinery when introducing new machines or work processes. Elimination measures are perceived as the most effective way to control noise. However, in iron and steel factories, elimination of noise due to the inherent characteristics of production machinery is practically infeasible [17].

Engineering measures involve actions that reduce noise being generated and or transmitted to the receiver. These encompass, for example, modifying the design of machinery, tools, processes and equipment; substitution, i.e. replacing a noisy process, material, tool or equipment with a quieter one; redesigning equipment to eliminate noise source; re-designing work layout; regular equipment and machine maintenance; introducing cushioning materials; enclosing noisy machinery with sound-absorbent materials; and introducing barriers such as walls [23, 79]. In some instances, potential obstacles to engineering noise controls such as lack of noise reduction options (quieter machinery), weak technical skills and experience and feasibility issues have been reported [80]. The recent systematic review of intervention studies employing engineering controls in workplaces indicated varying results, and more intervention studies are recommended [81]. However, these are the preferred measures for noise control despite the costs and technological challenges. Furthermore, in some classifications, substitution measures are grouped together with elimination measures.

Administrative measures are employed whenever engineering controls are not feasible. These include changes in the work schedule, management policy or operations that reduce the worker's exposure to occupational noise. Such measures comprise introducing rest breaks away from noisy areas; identifying, sign posting or zoning noisy areas; job re-designing to allow few workers into noisy areas, shortening shifts and modifying work schedules [23]. The implementation and success of administrative measures requires the commitment of management, regular follow-ups and workers' compliance.

Use of hearing protection devices (HPDs). These are measures (ear plugs, canal caps and ear muffs) designed to protect worker from the adverse effect of noise exposure during work. Each of these has pros and cons that vary according to worker activity, tools, equipment and the work environment. In principle, the workers' use of HPDs should attenuate occupational noise exposure at least down to a level below the recommended OEL. They are ranked as a last option in the hierarchy of noise control, i.e. when all other noise control measures are not feasible. Mild impact has been reported in the effectiveness of using HPDs among construction workers in the USA, although its effectiveness largely depends on training and their proper use [82]. However, in a well implemented hearing loss prevention programme (HLPP), the use of HPDs was associated with less NIHL [81].

The Hearing Conservation Programme (HCP) is the recommended workplace noise intervention designed to protect workers exposed to significant noise above OEL (85dB(A)) from developing or reduce the progression of NIHL [83]. Before its introduction, all workers at risk need to be identified. The programme comprises a series of interconnected steps that involve both the workers and employers in collaboration to improve results (figure 2). Such steps involve an initial audit of workplace procedures (assessment of noise risks), design and implementation of noise control measures (engineering, administrative, use of HPDs), health surveillance for workers at risk (audiometric evaluation and monitoring of workers' hearing), record keeping, and programme evaluation (Figure 2) [44, 83]. Implementation of HCP has been successful [84]. However, the effectiveness of HCP largely depends on effective worker education regarding all aspects of the programme, and there is a need for support from management, policies, availability and use of HPDs and motivations including incentive packages [23, 85-87].

In Tanzania, the Occupational Safety and Health Act (OSHA) No. 5 of 2003, requires the employer to provide and maintain effective personal protective equipment (including HPDs) for the use of employees, and that a thorough pre-placement and periodic medical examination (including ear screening in this case) should be conducted [88]. However, access to occupational health and safety services in the working community is still low, and raising awareness remains problematic [56]. These factors may result in difficulties implementing and achieving the intended outcomes in workplaces.

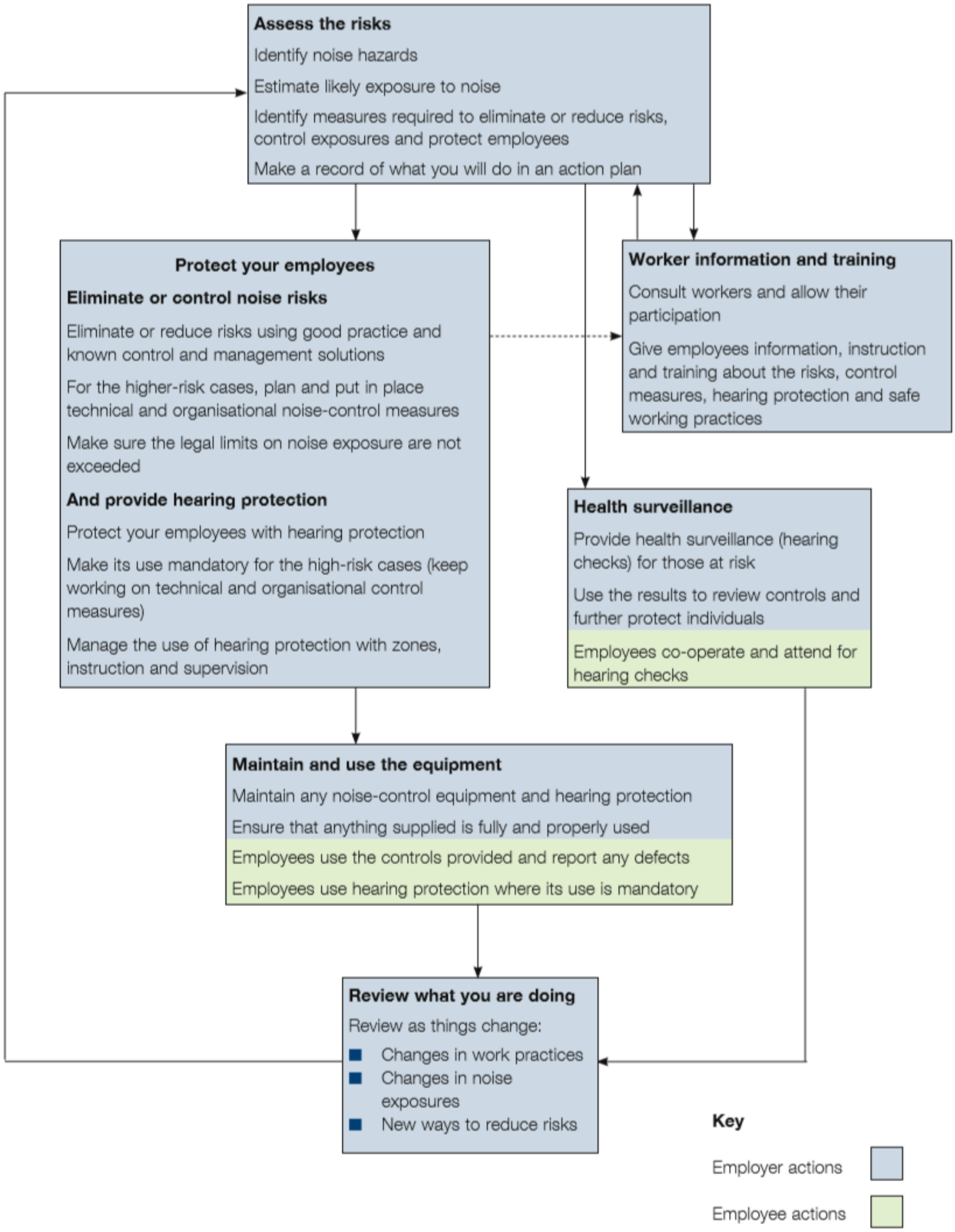

Figure 2. Schematic diagram showing HCP steps towards managing noise risks in the workplace (adopted from HSE- Control of noise at work regulations 2005, guidance to regulations) [44]

1.9 An overview of the Iron and Steel manufacturing industry

The use of iron and steel materials has a long history and has contributed much to industrial development and current global economic growth. The world yearly blast-furnace iron (pig iron) production has increased from 505,944,000 tonnes in the 1980s to 1,183, 451, 000 tonnes in 2014. Out of this, Africa as a whole produced 5,540,000 tonnes in 2014 [89]. The observed high production rate is highly correlated with market demand, production technology and economic advancement. However, it is noteworthy that the steel industry employs a significant number of workers. This sector needs capital investment in terms of labour, financial investments and technology which in turn necessitate better occupational health services in place to prevent workers from exposures to hazardous noise.

The steel manufacturing industry is said to be the second largest industry in the world behind oil and gas, providing employment for some fifty (50) million people [90]. It is estimated that the products from the steel manufacturing industry may be recycled; from 50% for electrical appliances, up to 85% for construction, up to 90% for machinery and up to 100% for automobiles in different countries of the world [91]. Due to increasing global demand, the yearly production has been doubled in the past fifteen years, i.e. from 850 million tonnes in 2000 to 1,665 million tonnes in 2014 [90].

In Tanzania, it is believed that carbon steel production through pre-heated draft furnaces was already practised around 2250 years ago (during the Iron Age) by the Haya tribes, west of Lake Victoria [92]. After independence, several changes have taken place in Tanzania. The first formal iron and steel industry (Aluminium Africa Limited-ALAF) was established in 1960 followed by the National Steel cooperation (under National Development Corporation-NDC) in 1966 and Steel Rolling Mill in 1970.

To date, more than 25 large steel-iron manufacturing industries exist, producing more than 200,000 tonnes of steel iron per annum. It was estimated that the construction industry accounted for up to 8.3% of the national revenues in 2013 [93]. Currently the most reliable raw materials for these industries are metal scraps and imported steel billet sheets. However, following the discovery of Liganga iron ore and construction of the steel plant, the production and raw materials are expected to increase dramatically (52,53).

1.10 Overview of studies on occupational noise exposure on and NIHL among steel workers in developing countries 2003-2015

Studies show that metal workers including iron and steel factories in industrialized countries are among the workplaces with high noise levels [17, 18], but only a few studies have been conducted in developing countries. There is only one accessed study in Tanzania on noise exposure in small-scale industrial areas with metal works and fabrications [94-98]. Also, research findings indicate that workplace noise exposure and related NIHL seems to decrease in the developed world, likely due to improved prevention measures, in contrast to the developing regions [18]. However, effective noise control measures in workplaces remains a major challenge across the globe, and further studies are recommended [81, 99].

In a literature search through Ovid Medline, nine studies published in English between 2003 and 2015 were retrieved on occupational noise exposure and NIHL in iron and steel factories (Table 2). These studies were from Africa and Asian regions classified as LMICs presumably due to the shift of manufacturing industries from industrialized economies to developing and emerging industrial economies [25]. Two studies were from India [100, 101] and one study each in the following countries: Saudi Arabia [98], Nepal [102], United Arab Emirates [103], Iran [104], Nigeria [96], China [105], and Tanzania [106]. Among these studies, only two studies were conducted on the African continent, which supports the claim of a current lack of information on occupational noise exposure levels and magnitude of NIHL among iron and steel workers in Africa, whereas industrial investments are concurrently on the rise. In all studies, noise levels were assessed by using SLM (device stationed at workstations or close to worker’s ear) and recorded noise levels were assumed to represent workers’ noise exposure while none of these studies used personal noise dosimeter. The latter is despite the recent consensus that dosimetry is the preferred method for assessment of personal noise exposure in the workplace [107]. Findings from these studies show that iron and steel workers were exposed to noise levels above the recommended OELs, indicating that noise may still be, to date, an inherent characteristic of this type of factory and hence noise-preventive measures would be necessary from the inception of steel/rebar production activities.

Regardless of the definition used in accessed studies, the prevalence of NIHL was above the global average of 7-21% with a wide range of 28% and up to 90% (Table 2). The same high prevalence was reported even when workers were reported to use hearing protective devices. This calls for more research on the effectiveness of these preventive measures.

Table 2. An overview of studies on occupational noise exposure and NIHL among iron and steel (metal) workers from 2003-2015

Author, Year & Country	**Study design, study population**	**Area level** (L_{Aeq}) **in dBA**	**Definition of HL**	**Prevalence of NIHL**	**Hearing protection devices**
Agarwal G, 2015 [100] India	Cross sectional, steel factory workers, N=341	65.0-92.0	An average hearing threshold levels > 25dB hearing level at 0.5, 1, 2, and 4kHz in the right and the left ear separately (using Pure Tone Audiometry)	40% for the Right ear, 46% for the Left ear	No information on use of hearing protection devices.
Noweir MH, et al. 2014 [98] Saudi Arabia	Noise survey/mapping, Metalwork industries i. Steel sheets forming and processing industries ii. Steel reinforcement forming for concrete industries	i. Steel sheets industries = 86.7-90.9 ii. Steel reinforcement industries = 90.5-95.0	-	-	Author recommend wearing hearing protection devices at higher noise level above 100% dose.
Whittaker JD, et al. 2014 [102] Nepal	Cross sectional, Small scale Metal/steel industry, (N= 115)	65-85	The peak threshold between 3 and 6kHz (an increased threshold within this range that reduced again at 8kHz) (using Pure Tone Audiometry)	30%	Ear protection devices provided
Singh LP, et al. 2013 [101] India	Iron and steel industry -Noise exposed workers engaged in various processes of casting and forging industry (N=165)	60-105	An average hearing threshold levels > 25dB hearing level at all measured frequencies (0.25 – 8.0 kHz) (using Pure Tone Audiometry)	90%	17% used hearing protection devices

Ahmed HO, 2012 [103] United Arab Emirates (UAE)	Cross sectional Iron and steel factory	70-96	-	-	45% had never used hearing protective devices
Attarchi MS, et al. 2010 [104] Iran	Cross sectional, Steel industry (N=310)	≥85	Significant Threshold Shift (STS): An average hearing threshold levels > 25 dB hearing level in either ear at frequencies 3,4,6 and 8kHz. (Pure Tone Audiometry)	41% in 2009	Hearing protection devices worn
Ologe FE, 2006 [96] Nigeria	Cross sectional, Steel rolling mills (N= 103)	49 - 93	An average hearing threshold levels > 25 dB hearing level in either ear at frequencies 0.5-4kHz, classified from mild to profound hearing loss. (definition not stated). (using Pure Tone Audiometry)	28% for the better ear and 57% for the worse ear	No information on use of hearing protection devices
Nomura K, et al. 2005 [105] China	Cross sectional, Metal workers (N=189)	85-95	A person unable to hear 40dB audiometric test sound at 4kHz	64% among noise exposed workers	Hearing protection devices worn
Minja BM, et al. 2003 [106] Tanzania	Cross sectional, Small scale industrial areas A. (Including Metal works) (N for A=124) Area A: metal fabrication, black smithery, carpentry and tailoring of motor vehicle accessories, small shops for marketing products.	68-86.8	Not defined Ear screened by Pure Tone Audiometry	51%	No hearing protection devices worn

2.0 KAP regarding occupational noise and NIHL

At workplaces, we would like to effectively control hazards such as occupational noise and reduce the risk of NIHL. Behavioural interventional measures to reduce hearing loss such as administrative measures and the use of HPDs require both the employers and workers to have a better and common understanding. It may not be good enough to just inform workers about risks for development of NIHL or use of legislations and expect to have a successful noise control intervention, other actions are needed to change their behaviour. Workers involvement in planning and implementation of noise control measures is therefore necessary. This is because some immediate intervention in working environments with high noise levels above OEL would require workers to be provided with and wear HPDs which will require their compliance and hence change their behaviour into good practice.

In this case it is necessary to establish what workers know, to observe and document their practices and assess their attitude towards occupational noise and NIHL. To come up with such useful information, a KAP survey could be used. A KAP survey is defined as a quantitative method (predefined questions formatted in standardized questionnaires) that provides access to quantitative and qualitative information which reveals misconceptions or misunderstandings that may represent obstacles to the activities that we would like to implement, and potential barriers to behaviour change [108]. The KAP model has three interrelated domains, i.e. knowledge, attitude and practice explained below and illustrated in figure 3.

Knowledge may be explained as a belief that is correct, justified and retained acquired through learning, practice and experience [109]. Knowledge is believed to provide human lives with orderliness which in turn affects behaviour. In research, explicitly knowledge at an individual level may be assessed in several ways such as self-report using questionnaire, quantitative and or qualitative surveys, free elicitation and paper-and-pencil tests. However, validity of results highly depends on the study design, tool used and characteristics of participants [110]. The main hypothesis when studying health-based knowledge in many populations, for example workers in iron and steel factories, is that there appears to be a direct relationship between knowledge and behaviour [111], but that relationship involves many other factors. Nevertheless, knowing what workers know about noise exposure and NIHL is the pre-requisite in planning for appropriate and effective control measures at workplace. This also helps to identify areas where information and education are most needed.

Attitude refers to a hypothetical construct, namely a tendency to evaluate some object in a favourable or unfavourable manner [112, 113]. Attitude consists of affect, cognition and behaviour and is normally linked with knowledge [112, 114]. Various techniques are available to measure attitude, for example explicit self-report (Thurstone, Guttman and Likert Scales), implicit attitude measures (response time measure, response facilitation measure and response competition measure), psychophysiological measures (measurement of brain activity, assessing changes in individual's physical expression in response to an attitude) and behaviour observation [113]. These methods are context-sensitive, and they are likely to give varying conclusions. However, as one of the strategies towards behaviour change, the World Bank (WB) recommends measuring existing attitudes before attempting to change them [115].

Practice reveals the acquisition of knowledge and any change in attitude caused by removal of misconceptions about a specific problem or disease that translates into preventive behaviour [112]. Practices include observable actions in response to an intervention. This can be measured by questionnaire and be substantiated by observational methods.

The three domains (knowledge, attitude and practice) form the so called KAP model which is useful in studying human behaviour when affected by a problem or a disease [112]. The theory postulates that the three domains are related, and that knowledge and attitude are likely to influence practice [111, 112]. In our case, therefore, the workers' knowledge and attitude towards occupational noise, NIHL, audiometry and the use of HPDS are likely to influence practices; for example, implementation of the occupational noise control measures including the use of HPDs (Figure 3).

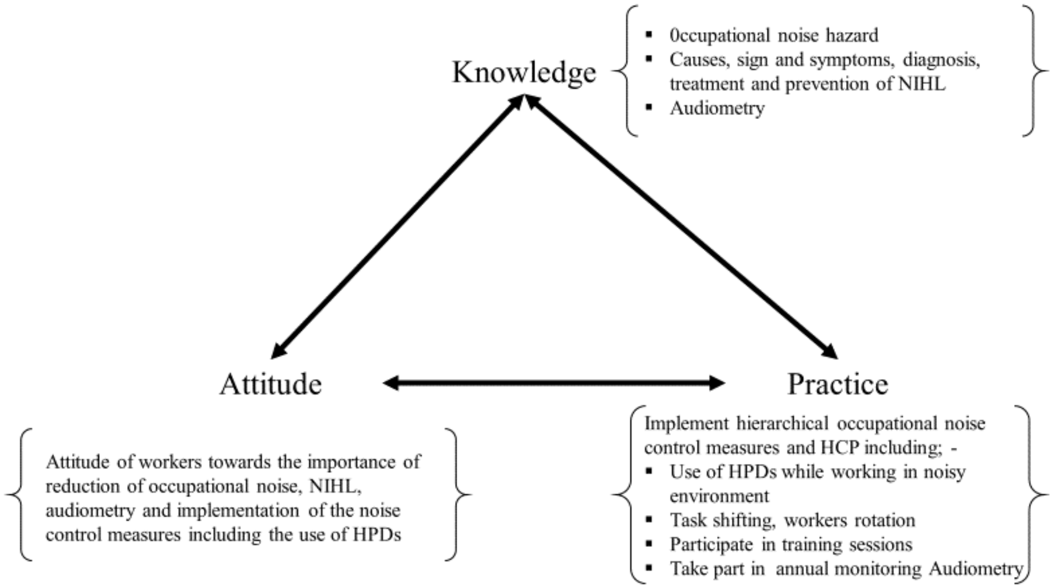

Figure 3. An illustrative KAP model for occupational noise and NIHL. The model is modified from cognitive-affective-behaviour theorem [1, 2]

KAP studies are conducted to collect information from a specific sample of a population about what is known, believed and done in relation to a particular topic [116]. In this present study, the goal is to acquire information pertaining to occupational noise exposure and related NIHL. Results from KAP studies help to bridge the knowledge gap, identify needs and barriers, attitudes and practices that are commonly shared. This information is useful for stakeholders (owners, workers and policy/decision makers) in planning and implementing noise control measures in the workplace. In addition, results may be used in selecting the most appropriate and cost-effective strategy [116], and in evaluating educational and communication interventions [117]. KAP studies have been reported to be more cost-effective and resource-conserving than other social research methods, because they are tightly focused and limited in scope [111, 112].

NIHL among workers has been linked with individual workers' knowledge of health and their attitude towards it. These may affect practices at work, although behavioural changes normally take a long time to manifest themselves [118]. Increased prevalence of NIHL has been related to a low KAP score among workers. For instance, a cross-sectional study of 97 Malaysian quarry workers found a prevalence of NIHL (57%), while the KAP scores were low, i.e. 11% for knowledge, 10% for attitude and 28% for practice [119]. Two studies on NIHL and occupational hazards respectively, in Malaysia and in Nigeria, found good knowledge, a positive attitude but poor practice among workers [120, 121].

2.1 Project rationale

Occupational noise exposure and related hearing loss (HL) are prevalent and the second most commonly reported occupational related injuries or illnesses in workplaces worldwide [7]. Workplace noise exposure above 85dB- time weighted average (TWA) over 8-hours is associated with increased risk and severity of NIHL. In the USA, for example, it is estimated that 8% of the workers exposed to 85dB(A), 22% of the workers exposed to 90dB(A), 38% of the workers exposed to 95dB(A), and 44% of those exposed to 100dB(A) are likely to develop NIHL within ten or more years of occupational noise exposure [6, 122]. NIHL presents a public health problem that is chronic and has an irreversible effect on human hearing. Its consequences include loss of productivity, social isolation, impaired communication between the affected person and co-workers and family members, with the accompanying potential to cause accidents and injuries, impair one's ability to monitor the work environment, decreased self-esteem and heighten expenses for workers' compensation and hearing aids [14]. Its prevalence is highest in LMIC countries, including Tanzania, partly because of industrial investments with lack of preventive services and limited resources [7, 14, 54, 96, 123]. Iron and steel factory workers are likely to be at higher risk of hearing loss as the result of a poor and uncontrolled high-noise working environment. In Tanzania, there is to our knowledge no accessed published studies on occupational noise exposure levels and hearing loss in this sector. The iron and steel industry sector is growing rapidly and employs a significant number of workers. Also, little is known about the knowledge workers have about noise exposure in workplaces. This information is fundamental in designing workplace preventive interventions, policy making and focused research in the country.

Due to rapid major investments in the industrial sector in Tanzania, a significant number of workers employed in iron and steel industries are likely to be exposed to high noise levels. Lack of reliable information on noise as an occupational hazard and the prevalence of NIHL among workers; unavailability or poorly implemented hearing conservation programme; low access to health and safety services including poor knowledge and use of HPDs hamper efforts towards improving the working environment.

This project was therefore aimed at documenting the noise exposure levels and the magnitude of NIHL among workers in iron and steel industries in Tanzania and furthermore to provide information regarding KAP to guide policy dialogues among stakeholders and help in decision-making process targeting hearing conservation in workplaces.

3.0 Objectives

3.1 Main objective

The main objective of this thesis was to gain knowledge about occupational noise exposure levels and NIHL among iron and steel workers in Tanzania. This information would be relevant for planning and implementing noise control measures in workplaces.

3.2 Specific Objectives

i. To document occupational noise exposure levels and to identify potential determinants of noise exposure in iron and steel factories.

ii. To determine the prevalence of NIHL among iron and steel workers, and to compare the hearing thresholds at different frequencies between these workers and a control group exposed to a low level of occupational noise, and

iii. To assess the level of knowledge, attitude and practice regarding noise exposure, NIHL and the use of hearing protection devices among iron and steel industry workers in Tanzania.

4.0 Materials and methods

4.1 Occupational noise exposure and the NIHL project

In 2015, the project ‘Occupational noise exposure and hearing loss’ was established and implemented by the University of Bergen, Norway in collaboration with The Muhimbili University of Health and Allied Sciences (MUHAS), Occupational Safety and Health Authority (OSHA) and Iron and Steel Factories in Tanzania.

4.2 Study setting

We obtained a list of 22 registered iron and steel factories in the Eastern Tanzania Zone from the headquarter of the OSHA-Tanzania. We examined these factories individually to ensure that they were operational and accessible. Also, we checked whether they had complete steel production processes, a known factory address and at least 50 permanent employees. Twelve factories qualified. Of these, we selected five factories randomly for the study. We had initial contact with the selected factories between December 2015 and January 2016. One factory changed production just prior to project start-up and was therefore excluded from the study. Thus, we were left with four factories.

4.3 Iron and steel manufacturing in Tanzania

The manufacturing process in the four steel factories is divided into two separate sections – the furnace section, where metal scraps are processed into steel billets (ingots), and the rolling mill section, where steel bars (rebars) are manufactured. Each section has several job groups assigned different tasks which may result into difference in their noise exposure levels (Table 3)

The raw materials commonly used are domestically available metal scraps and imported billet sheets (figure 4&5). In the furnace section, metal scraps are fed into and melted in the induction furnace to form molten steel with floating furnace slag which is removed by raking (Figure 6). The molten steel is then refined by the addition of gases such as carbon dioxide and nitrogen at the base of the furnaces (54). A sample of this slag is tapped and sent to the laboratory to be checked for its carbon and other impurities content (according to the steel production standards). Normally it is estimated that the carbon content in the final steel should be adjusted to 0.04% (55). The molten steel is then poured into a ladle and then into smaller ladles/crucibles that are carried manually to the prepared moulds of varied sizes to form steel billets (Figure 7). The billets are cooled and later weighed before they are sent to rolling mill processing [124, 125]. Noise is emitted by the machines and manual handling of metal scraps, steel billets and feeding metal scraps into the furnace oven. Other sources of noise include the weighing process and the moving and dropping of billets onto the weighing scale (Table 3).

The rolling mill process involves heating steel billets to a temperature of about 960ºC in a gas furnace, after which the billets are transferred as red-hot bars to a roughing machine, where they are shaped and lengthened. Electric motor-operated conveyor rails transport the hot steel billets between the machines. The red-hot bars are fed into six serially arranged rolling mill machines where steel rebars are manufactured as needed (Figure 8). Normally, the width of rebars range from 8, 10, 12, 16, 20 to 25mm depending on the purpose. Very wide rebars are weighty and are likely to increase noise during production. Rebars are then moved into a cooling bed and cut into standard lengths (normally 6 metres) (Figure 9). The large cutting machine produces more noise than the smaller cutting machine. In addition, all these processes involve noise emission from the operating machines, movement of materials and the operating tasks (Table 3). The products are bend-tested to ensure conformity with required standards. The final products are bundled and stored for transport.

Figure 4: steel billets made from domestic scraps: Two different billet weights (100-120kgs vs 20-30kgs) were used in the rebar production process. The large billet weight was related to higher noise levels that the smaller billet weight.

Figure 5: imported steel billet sheets, normally cut into larger billet weight for rebar production

Figure 6: feeding a furnace oven with metal scraps: droning noise from operating furnace, noise from collision of metal scraps during furnace feeding, loading handcart and siren. Noise from explosive materials accidentally fed into the furnace.

Figure 7: Pouring molten steel into moulds

Figure 8: steel manufacturing using a rolling mill machine: Droning noise from multiple operating six-strand rolling machines, flywheels, electric fans, motors, conveyor rails, frequent collision of metal rods in motion and hammering.

Figure 9: steel cutting into 6-metre length: large cutting machines produce higher noise levels than the smaller cutting machines

Table 3. Description of job group, tasks and noise sources among workers in iron and steel factories in Tanzania

Section	Job group	Main Task	Sources of noise
Furnace Section	Melters	Offloading metal scraps using cranes, final sorting of metal scraps to remove explosives, feeding the induction furnace oven with raw materials using hands, handcarts and crowbars.	Droning noise from operating induction furnace plant. Noise from collision of metals scraps during offloading by overhead crane, loading and offloading into handcarts, loading of metal scraps into furnace, siren. Noise from explosive materials accidentally fed into furnace.
	Moulders	Pouring molten steel from ladle to turn dish and then transfer by crucibles to moulds where it cools to form steel billets.	Noise from siren and noise generated from induction furnace section as these two are under same roof except for factory B.
	Billet shifters	Transfer of steel billet from the furnace section to the pusher.	Noise from siren, weighing billets, and loading billets into handcarts transported to pusher section. Noise generated from induction furnace.
	Workers at billet weighing	Weighing and recording steel billets for the steel production process.	Noise generated by putting billets on the weigh scale and loading billets into handcarts transported to pusher section.
	Workers at continuous casting machine (CCM) (available only in factory C)	Operate an automatic machine that receives molten steel to form steel billets.	Droning noise from CCM machinery. Noise from adjacent induction furnace, siren, pusher, and rolling mill sections (as they are all under same roof). Reflective sounds.
Rolling Mill Section	Pusher	Feeds reheating gas furnace with billets at charging side.	Droning noise from operating gas furnace, offloading billets from handcarts, loading of billets into the pusher machine. Noise from adjacent operating rolling machines, electric fans, siren and motors. Reflective sounds.
	Firemen	Controlling reheating billets into red-hot process. Removing red-hot billets from gas furnace using crow bars and direct them into an electric operated metal conveyor.	Same as pusher. Noise from collision of red-hot billets, conveyor rails and sides.

Workers at roughing	Flatten red-hot billets (back and forth) into thinner and more elongated shape than the original steel billet.	Same as in Firemen. Noise from pressurizing/flattening process.
Tongs men Machine operators (in factory C)	Steel bar rolling mills.	As in roughing section. Noise generated from frequent metal impact from moving metal rods into rolling mills and the conveyor system and from the hammering of metal rods stuck in the machines.
Workers at cooling bed	Moving hot steel bars from rolling machines into a cooling platform.	Droning noise from rolling mill and cutting machines, siren, reflective sound, moving hot steel bars through metal conveyor beams and rails.
Cutters/bundlers	Cutting steel bars into required length (normally 6 metres) and bundling steel bars for storage/transport.	Noise from cutting machine, moving steel bars into conveyors. Noise from rolling mills machines. Loading of finished products immediately after cutting sometimes produced noise.
Shearers	Cutting rejected steel bars into chunks for recycling.	Droning noise from the operating machines, siren. Noise from pieces of steel dropped into carrying buckets.

4.4 Study design

The project comprised an exposure study (Paper I) and a cross sectional study with two parts involving audiometry (Paper II) and interviews on questions regarding KAP (Paper III) conducted among noise exposed male production workers from four iron and steel factories located in different industrial areas in Dar es Salaam, Tanzania. The fieldwork was conducted between June 2016 and June 2017. In the study to establish the magnitude of NIHL (Paper II), male teachers from public primary school made up the control group. To achieve the planned main objective, the project goal was divided into three specific objectives that were accomplished through various scientific methods for the different outcomes (Figure 10).

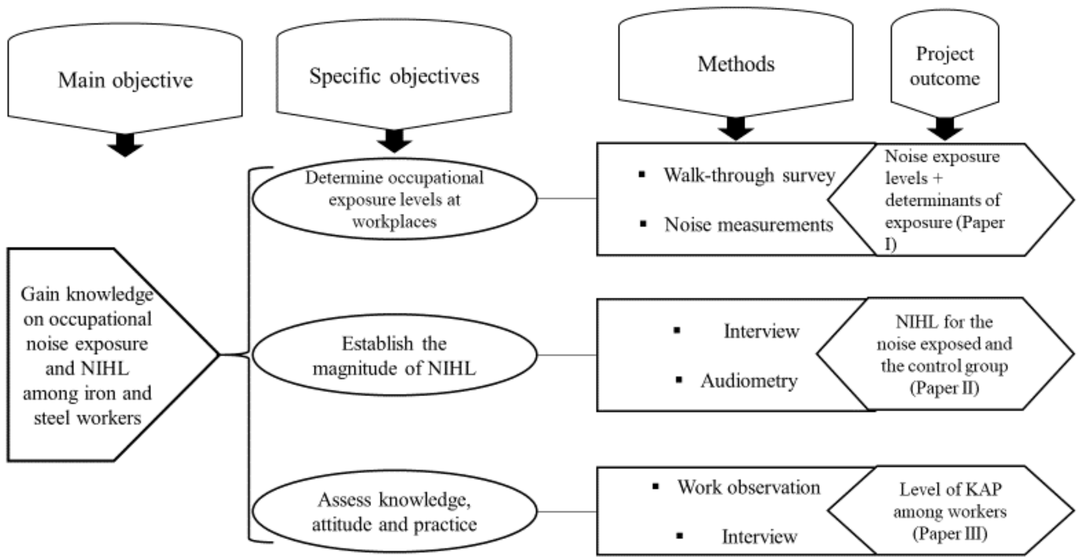

Figure 10: Schematic diagram of occupational noise exposure and the NIHL project among iron and steel workers in Tanzania

4.5 Study population

We conducted a study involving 253 randomly selected workers in the production line, i.e. 71 in factory A, 57 in factory B, 61 in factory C and 64 in factory D. In addition, 123 randomly selected male teachers from 34 public primary school made up a control group (Figure 11).

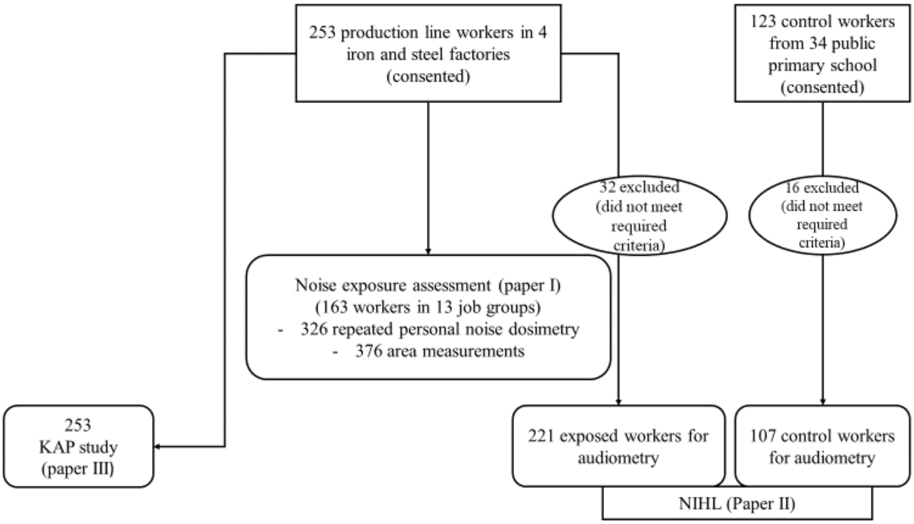

Figure 11. Flow chart describing the participants in the occupational noise exposure and hearing loss among iron and steel workers in Tanzania

4.6 Participants

Our participants were male workers in the production line. We did not encounter female workers except in other sections performing administrative services. The control group in Paper II comprised male workers randomly selected from the teachers in public primary schools. Since there was no available information about hearing loss among noise exposed workers or among the general population in Tanzania, the sample size was calculated based on a community baseline survey conducted in Uganda that found the prevalence of hearing loss among adults to be 12% [51]. In our study the effect of noise on hearing loss was hypothesized to be doubled, i.e. 24%. To achieve 90% power and be able to detect a difference in hearing loss between noise exposed workers and a non-exposed group at a significance level of 0.05 (Using Open-Epi online calculator Version 3.3a) [126], a total number of 230 exposed workers were needed. We added 10% to account for non-responders, providing a total sample size of 253 workers.

We held meetings with both management at the individual factories and the administration at the public primary school. We presented the purpose of the project and asked for a research permit. Each of these partners referred us to a contact person who helped the research team in planning the research activities. We were provided with a list of permanent workers by each factory management team and by the administration of the primary schools. We randomly selected a total of 376 workers (253 workers from the four iron and steel factories and 123 teachers from 34 public primary schools) using a table of random numbers. We invited the selected workers to participate in the study. These workers were informed about the project objectives and were required to give written consent (Annex I).

All selected workers consented to participate in the study. The 253 workers from the four iron and steel factories exposed to noise at work gave their consent and participated in the KAP study (Paper III). The same participants formed the noise exposed group for the NIHL study (Paper II) in which we had, in addition, the control group consisting of 123 male teachers from public primary schools. The latter were hypothesized to have a lower levels of noise exposure at work (Figure 11). In the NIHL study (Paper II), we excluded 32 and 16 workers respectively from the noise exposed group and the control group based on exclusion criteria [49, 70]. We used information collected through a structured interview to exclude those with congenital hearing loss (n= 1) and a history of otitis media during childhood (n= 6) [70]. Five workers were on sick leave and could not be present for audiometry. In addition, 20 workers who initially consented to participate in the study changed jobs and could not be located during the audiometry testing. Among the controls, three workers were not accessible; one had retired; three been transferred to other schools; one worker had incomplete audiometry because of an electrical power cut, (electrical outage) and was not accessible for a new test, while two workers declined to participate in audiometry. Before analysis, we excluded those who reported using long-term medication (n = 4) because the participants did not have adequate knowledge of the type of medication they used [50]. Thus, we were left with a total of 328 participants, i.e. 221 exposed and 107 control workers for the NIHL study (figure 11).

For the exposure study (Paper 1), workers in same job group/title, i.e. those doing similar tasks in the same working area, were assumed to constitute similar exposure groups [127]. We had a total of 13 job exposure groups according to their jobs, i.e. melters, moulders, billet shifters, workers at billet weighing and workers at continuous casting machines (CCM) in the furnace section; and tongs-men, pushers, firemen, cutters, workers at the cooling bed, workers at roughing, rolling mill automated machine operators and shearers in the rolling mill section (table 3). We aimed at randomly selecting 5-10 workers from each job group in each factory. However, the number of workers in each job group and the number of job groups respectively varied within the factory and between factories. Thus, we ended up with a total of 163 workers from the four factories, i.e. 46 from factory A, 43 from factory B, 34 from factory C and 40 from factory D.

4.7 Interview questionnaire and checklists

For the KAP study (Paper III), we modified and used a validated, structured questionnaire from a study of sawmill workers in Malaysia to collect information from participants through an interview [120, 128]. Statements regarding legislation in Malaysia were modified into neutral statements unrelated to any country law. The statement asking for hobbies was modified to omit the word ‘scuba’, adding ‘listening to loud music for long time’ instead. The word ‘sawmill’ was omitted, and the word ‘deafness’ was translated into ‘hearing loss’. The English version of the questionnaire was translated into Swahili and then back into English to check for logical consistency and meaning. The modification was so done to suit the local context. In addition, the questionnaire collected demographic characteristics of the participants, i.e. factory identification, age in years, educational level (no formal education, primary education, secondary and tertiary education), working section (furnace section, rolling mill section). The complete questionnaire is provided in Annex IIa and Annex IIb.

Workers’ knowledge regarding NIHL was assessed using 18 statements, each with a score of ‘1’ for correct response and a maximum score of 18 points, equivalent to 100%. The 18 statements in the knowledge domain were for collection of information on the causes, symptoms, treatment and prevention of NIHL.

Workers’ attitudes to the importance of noise reduction at the workplace, NIHL, audiometry and wearing of hearing protection devices were assessed by 13 statements, using a five-point scale ranging from ‘strongly disagree’, ‘disagree’ and ‘neither disagree or agree’ to ‘agree’ and ‘strongly agree’, each with a corresponding score of between one and five. The maximum score was 65 points, equivalent to 100%.

Workers’ practice regarding provision and use of hearing protection devices, health and safety training and audiometry were assessed using 12 statements with the three possible responses ‘always’, ‘sometimes’ and ‘never’, and with scores of 3, 2 and 1 respectively. The maximum score was 36 points, equivalent to 100%.

For Paper II, we also collected information on confounding factors for hearing loss that were necessary to control for during analysis [49]. These were duration of work, history of noise exposure, current smoking, current use of long-term medication, exposure to organic solvents, ear infections as a child or adult, injury/trauma, tinnitus, known congenital hearing loss, relative with hearing loss, history of ear-related medical condition and the use of hearing protection devices while working in noisy areas. The questionnaire used in the interview is found in Annex IIa and Annex IIb.

We used two separate checklists. The first was for the Walk-through survey in all factories (Paper I-Annex IIIa). We collected information about factory background including listed numbers of workers per each section, occupation noise-producing machinery and tools, available job groups, tasks, production capacity, shifts and shift pattern, presence of HCP and related training, availability of safety and health policy. In addition, we observed the availability and use of hearing protection devices during work. A second checklist was for screening workers on the audiometric day (Paper II- Annex IIIb). We asked and checked workers for symptoms of upper respiratory infections and ear discharge [129-131]. In addition, we recorded the time (in hours) and date they left work to check whether it complies with the requirement for audiometric screening protocol where a minimum of 12 hours out of the noisy environment was required.

4.8 Personal noise measurement

We conducted full-shift personal noise measurements using personal noise dosimeter (Brüel and Kjaer type 4448) according to ISO 9612:2009. The dosimeters had A-weighted noise level ($L_{p,\mathrm{A}}$) and a measurement range from 50-140 dB. A 3-dB exchange rate was used, and the dosimeters logged noise data each minute. The instruments were calibrated before and after the sampling period, and no shifts in baseline were detected. The dosimeters were attached to workers' shoulders approximately 10–15 cm from the ear. Workers were instructed to handle the dosimeters carefully while working, not to touch or shout into the microphone and to report any mishap with the instrument during the measurement period. During the sampling period, we checked two to five times to verify that the dosimeters were working properly. We instructed workers not to tamper with devices during resting periods. We recorded tasks performed by each worker on a sampling sheet including information on noise sources. The workers confirmed this information during lunch and at the end of the sampling period. The values recorded from the dosimeters were the start- and end-time of the sampling period, the A-weighted equivalent noise level for the duration of the measurement ($L_{p,\mathrm{A,eq}T}$) and the C-weighted peak noise level ($L_{p,\text{ Cpeak}}$). The average A-weighted daily noise exposure levels ($L_{\text{EX,8h}}$) were normalized to an 8-hour working day by job groups, working sections and factory, using the following equation:

$$L_{\text{EX,8h}} = L_{p,\text{A,eq}Te} + 10\log^{(Te/T0)} \quad (1)$$

where $L_{p,\text{A,eq}Te}$ is the A-weighted equivalent continuous sound pressure level from the dosimeter, Te is the measurement period and $T0$, is the reference duration, equal to 8 hours.

4.9 Area noise measurement

We conducted 376 area measurements using a portable, hand-held sound level meter (Brüel and Kjær type 2250), i.e. 130 measurements in factory A, 108 in B, 60 in C and 78 in factory D. The instrument was calibrated before and after each measurement day. The measurements were taken under apparently stable working conditions with the assumption that the measured result would be representative of the prevailing working conditions. The area measurement points were at an approximate distance of 2 metres from one another, and covered the whole working section allocated for the respective job groups (Figure 12). In physical hazardous areas, in which workers' sideways movements were limited, such as for tongs men, only points at each working position in a straight line backwards (approximate 2 metres) were measured. Thus, the total number of measurements was influenced by the size of the working area designated for each job group, the larger the working area, the higher number of measurements. The number of area measurements for the different working areas ranged between 5 (for shearers) and 83 (for moulders). Measurements were conducted in a single day in each factory, and once for each measurement point. Each measurement was taken for 10 seconds and A-weighted equivalent noise levels ($L_{p,\text{A,eq10s}}$) were recorded. For averaging the results in each work area, a quantity was calculated using the equation (1).

$$p^2/p_0^2 = 10^{(Lp,\text{A,eq10s}/10)} \quad (2)$$

where p is the sound pressure level corresponding to $L_{p,\text{A,eq10s}}$ and p_0 is a reference value set at 20 μPa. By using equation (2), a mean sound pressure level was calculated as:

$$\text{mean } L_{p,\text{A,eq10s}} = 10*\log(\text{mean}(p/p_0)^2) \quad (3)$$

The A weighted noise levels ($L_{p,\text{A}}$) were reported in decibel (dB(A)).

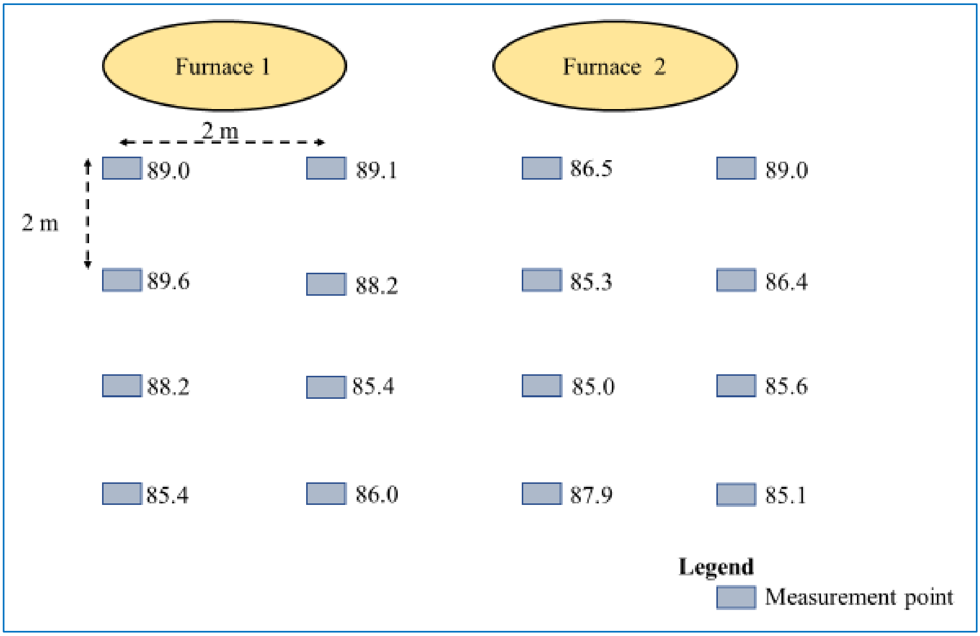

Figure 12: Illustration of area measurements performed using Sound Level Meter (in dB(A)) in factory A in the furnace section in a study among iron and steel factory workers in Tanzania

4.10 Pure tone audiometry

We conducted pure tone audiometry (PTA) in an ear-screening locally-constructed booth in a quiet room at the headquarters of the OSHA in Tanzania. We used an Interacoustics AD226 (Interacoustics, DK-5500 Middelfart, Denmark) with Amplivox Audiocup earphones having lower test limit of −10 dB. The equipment was pre-calibrated. Test frequencies were 250–8000 Hz in the order starting with 1000, 2000, 3000, 4000, 6000, 8000, 500, 250 and finish at 1000 Hz [70]. A manual test procedure was used in compliance with ISO 8253-1:2010 [70, 129, 130]. The same technical personnel conducted all audiometric tests using a standardized protocol. Background noise in the test booth was monitored by a calibrated hand-held Sound Level Meter (Brüel and Kjær, type 2250), and checked for conformity with ISO 8253-1:2010 standard [70]. For best results, audiometry was conducted in the morning before any work exposure.

4.11 Statistical analysis

Descriptive statistics were presented as means and standard deviation for continuous variables and frequencies or percentages for categorical variables (Papers I-III). All statistical analyses are summarized in Table 4.

In Paper I, we computed $L_{p,\mathrm{A}}$ for both area and personal measurements using Microsoft Excel Sheets. The difference between area and personal noise exposure was analysed using linear mixed effects model to account for repeated measurements within job groups and factories. Factory and job group were entered as random factors and sample type (personal/area) as fixed effects.

In preparatory analyses for noise exposure modelling for identification of determinants for noise exposure, potential, dichotomous noise determinants were dichotomized. The first group comprised factory-related determinants, i.e. size of the cutting machines (large/small); presence of roughing machine (yes/no); separated shearing machines (yes/no); steel billet weight (20-30kgs/100-120kgs); furnace installation (above ground floor/below ground floor); production capacity (5,400-15,400/80,000 tonnes per year) and rolling mill plant operation technology (traditional, manual/modern, automated). The second group comprised task-related determinants, i.e. manual handing of raw materials/billets/crowbars (yes/no); feeding the furnace oven (yes/no); pouring molten steel into molds (yes/no); billet weighing/transfer (yes/no); feeding re heating furnace (yes/no); feeding roughing machine (yes/no); work at rolling machines (yes/no); and steel bar cooling/cutting (yes/no). Independent sample t- test was used to analyse differences in noise exposure within each of these determinants. Linear mixed effects models were used to identify significant explanatory variables/determinants for noise exposure in the furnace and in the rolling mill sections, respectively. Personal noise exposure ($L_{\mathrm{EX,8h}}$) was entered as a dependent variable. Worker identification and factory were entered as random effects. Significant determinants ($p< 0.05$) from the initial t- test analysis (rolling mill plant technology, production capacity, furnace installation, steel billet weight, separated shearing machine, size of the cutting machine, manual handing of raw materials/ billets/crowbars, pouring molten steel into molds, billet weighing/transfer and feeding re heating furnace) were entered as fixed effects in two steps, starting with process-related and then task-related determinants. In addition, intercorrelation between determinants was tested using the Spearman correlation test. When two or more determinants correlated, we chose the determinant that contributed to the highest percentage of explained variability in noise level.

In Paper II, we defined NIHL as the hearing threshold level ≥25 dB hearing level in either ear at 3000, 4000 or 6000 Hz [43]. Potential determinants of hearing loss were identified. Age was categorized into three age groups (tertiles) based on the age distribution among the controls. Duration of work was categorized arbitrarily into three groups (≤2 years, 2–10 years, 11–37 years). History of ear-related medical conditions (diabetes, hypertension, ear infections and head injury) were combined as a dichotomized variable (yes/no), current smoking (yes/no), relatives with hearing impairment (yes/no), tinnitus (yes/no) and previous noisy work (yes/no). A chi-square test was used to explore the relationship between these variables and hearing loss in exposed participants compared with controls. The intercorrelation between participant's age and duration of work determinants was tested with the Pearson correlation test.

We used log binomial regression models with a 95% confidence interval (CI) to ascertain differences in hearing loss (yes/no) between exposed and controls within each age strata and within the total group of workers while adjusting for the significant determinants selected from Chi-square analyses and the correlation test.

We computed the mean hearing threshold for the different test frequencies for both exposed participants and controls, as well as for the three age groups within the main exposure groups. For each test frequency, multiple linear regression was used to analyse for differences between exposed and controls, while adjusting for age as a continuous variable, previous noisy work and history of ear-related medical condition.

We calculated the predicted noise-induced permanent threshold shift (NIPTS) corresponding to these three mean exposure durations according to ISO 1999 section 6.3, that provides a formula and method that predicts NIPTS at 1000, 2000, 3000, 4000 and 6000 Hz as a function of the logarithm of exposure duration (d) (in years), and the square of noise exposure level (L_{Aeq8h}), with frequency specific constants u, v, and L_0 (a sound pressure level, defined as a function of a given constant value for each frequency in decibels [71]:

$$\mathrm{NIPTS} = [u + v\log_{10}(d)]\,(L_{Aeq8h} - l_0)^2 \tag{4}$$

In Paper III, we computed the sum scores for the KAP domains, converted into percentages of the total score and then dichotomized, with knowledge and attitude scores of ≥ 75% being defined as good knowledge and positive attitude respectively [120] whilst the practice score of ≥ 50% was defined as good practice.

In the sum scores for KAP, we explored the differences between age and duration of work using one-way Analysis of Variance (ANOVA), whilst an independent samples t-test was used to analyse the association between sum score for the KAP and the continuous variables. Chi-squared test was used to analyse the association between dichotomized KAP domains and categorical variables. In addition, multiple linear regression was used to explore the relationship between attitude and practice scores, respectively and the significant variables from the preliminary analyses, i.e. educational level and the factory. In this analysis, three dummy variables were used for factory B, factory C and factory D. Factory A was used as reference. We evaluated the internal consistency in distinct items in each domain of knowledge, attitude and practice using Cronbach's Alpha coefficient (α), and the results were α= 0.74, 0.70 and 0.72 respectively.

In all statistical analyses, we used IBM SPSS Statistics, Version 24 & 25 (Allen & Unwin, 83 Alexander Street, Crown Nest NSW, Australia) and set a parameter of $p < 0.05$ as statistical significance. For Paper II, NIPTS was estimated using Microsoft Excel (Office 365, Microsoft Corporation, Redmond, WA 98052-7329, USA).

Table 4. Summary of statistical methods used

Statistical method	Paper I	Paper II	Paper III
Chi-square test		√	√
Independent sample t-test	√	√	√
One-way ANOVA	√		√
Pearson's correlation test		√	
Spearman correlation test	√		
Log binomial regression		√	
Multiple linear regression		√	√
Linear mixed effects model	√		
Cronbach's Alpha coefficient			√
Microsoft Excel	√	√	

4.12 Ethical clearance

We conducted the study in accordance with the Helsinki Declaration of 1975 and its subsequent revisions. We obtained ethical clearance from The Regional Committee of Medical and Health Research Ethics (REK-VEST) in Norway number 2016/635/REK sør-øst dated 20 May 2016; and The Muhimbili University of Health and Allied Sciences (MUHAS) Ethics Committee in Tanzania with Institutional Review Board (IRB) number 2016-06-24/AEC/Vol. XI/38 dated 24 June 2016. Each iron and steel factory (Papers I–III) and primary school administration (Paper II) was contacted individually, and all of them granted permission to conduct the study. Each individual participant was contacted and informed about the research objectives and activities to be conducted; all participants gave written consent prior to inclusion in the study. The information collected was treated as confidential. Workers with severe or profound hearing loss (defined as hearing threshold >60dB) were referred to a specialist for further examinations.

5.0 Results

5.1 Summary results in Paper I: Variability and determinants of occupational noise exposure

A total of 163 workers participated in this study with repeated personal noise measurement. The average personal noise exposure ($L_{EX,8h}$) was 92.0 dB (A) (n=326). The mean measurement time was 7.3 (SD=0.9) hours. About 90% of all measurements were above the OEL of 85 dB(A). There was a significant difference in average noise exposure among the four factories ($p<0.01$). Factory B had the highest equivalent noise exposure followed by factory C, while factory D had the lowest noise exposure Personal exposure was significantly higher in the rolling mill section (93.0 dB(A)) than in the furnace section (89.7 dB(A)). There was a significant difference at the $p < 0.05$ level in noise exposure among the 13 job groups ($p<0.001$). Thirty-three percent (n= 108) of the personal measurements had $L_{p,\,\mathrm{Cpeak}}$ exceeding 135 dB(C) of which factory A had the highest fraction (41%) while factory C had the lowest fraction (28%).

The average area noise level was 90.5 dB(A). Factory B had the highest average noise level while factory D had the lowest level. The personal noise exposure was significantly higher (2.6 dB (A); 95 CI = 2.1- 3.1) compared to the corresponding area measurements.

In the linear mixed effects models for noise exposure in the furnace, the three variables: furnace installation, billet weighing/transfer and manual handing or raw materials/ billets/crowbars were significant determinants and explained 40% of the total variance in noise exposure. Furnace installation below the ground floor was associated with a 2.3 dB(A) reduction in noise exposure whereas manual handling and billet weighing/transfer increased noise exposure by 2.2 dB(A) and 2.1dB(A), respectively. In the rolling mill section, the size of the cutting machine, the steel billet weight and feeding the reheating furnace were significant determinants and explained 46% of the total variance in noise exposure. Large cutting machines were associated with an increase of 1.8 dB(A) in noise exposure. Additionally, the large steel billet weight (100–120 kgs) was associated with a 3.6 dB(A) increase and feeding the reheating furnace with 1.9 dB(A) decrease in noise exposure.

5.2 Summary results in Paper II: Prevalence of NIHL

The participation rate was 87% for both the exposed [N=221] and controls [N=107]. The mean age was 32 (SD=8) years and 40 (SD=7) years respectively for the exposed and the control groups. The exposed group had a mean duration of work of 5 years (range: 0-24 years). The overall prevalence of hearing loss was significantly higher (Chi square test, $p = 0.003$) among exposed workers (48%, n=221) than among the controls (31%, n=107).

Results from the log binomial regression model, adjusted for age, previous noisy work and history of ear-related medical condition, showed a statistically higher risk of hearing loss among exposed workers compared to controls, with a prevalence ratio of 1.3 (95% Confidence Interval: 1.10-1.62). The mean hearing threshold between exposed and control workers at 3000, 4000 and 6000 Hz differed significantly (independent samples *t*-test, $p < 0.05$). In linear regression analyses within each age stratum, there were significant differences in hearing threshold between exposed and controls for the frequencies 4000 and 6000 Hz within the youngest age group (18–35 years) adjusting for age as a continuous variable, previous noisy work and history of ear-related medical condition. In analogous analyses, the hearing threshold for the frequencies 3000, 4000 and 6000 Hz were significantly different in the 36–43 years age group, and in the age group 44–59 years, only the frequency 6000 Hz was significantly different.

When comparing the hearing threshold with the predictions from ISO 1999, the mean hearing threshold among the exposed participants in the 18–35 age group was similar to the predicted NIPTS according to ISO 1999 at the lower frequencies (1000, 2000 and 3000 Hz), while it was about 1 dB higher than ISO 1999 for the higher frequencies (4000 and 6000 Hz). For the 36–44 and 45–59 age groups, the hearing threshold for the higher frequencies were lower (3, 1 dB and 6, 4dB lower, respectively) for same frequencies than the predicted NIPTS in ISO 1999.

5.3 Summary results in Paper III: KAP study

The participation was 100% [n=253]. Sixty-seven percent had received primary education. The mean scores for attitude and practice differed significantly between the four factories (one-way ANOVA, $p<0.001$). Factory A had a significantly lower mean attitude score than the other three factories, whilst there was no significant difference between those other three factories. The mean practice score for Factory D was significantly lower than for the other three factories (A, B and C), whilst there was no significant difference in mean practice scores between those three factories. The mean knowledge scores did not differ between any of the four factories (one-way ANOVA, $p> 0.05$).

Overall, the mean score for knowledge did not differ significantly between the subgroups for age, duration of work and educational level. There was a significant difference in attitude scores between participants who had received primary education and those who had received secondary and tertiary education (independent samples t-test, p=0.01). The participants who had received primary education had a significantly more positive attitude than those who had received secondary and tertiary education (chi-square test, p<0.05). In the practice domain, participants who had received primary education had significantly lower scores than their counterparts (independent samples t-test, p=0.03). The overall mean scores for practice was low.

A high proportion of the participants had a poor overall knowledge of the specific causes of NIHL. For example, only 16% responded correctly to the statement 'HL may occur due to high-impact noise exposure, e.g. gunfire, and 45% to the statement 'HL may occur if an individual is continuously exposed to a noisy environment'. Regarding NIHL symptoms, 88% responded correctly to the statement 'Poor hearing of normal speech is a sign of HL' and 79% to the statement 'Ringing in the ear is the sign of HL'. Nevertheless, only 33% responded correctly to the statement 'HL due to noise exposure is permanent', 21% to the statement 'HL due to noise exposure cannot be treated by using medicines' and only 14% to the statement 'Stopping working in high noise level results into complete recovery when you have acquired HL'. Regarding prevention, 87% responded correctly to the statement 'Wearing earplugs/earmuffs prevents HL', 43% to the statement 'Encapsulating the noisy machines reduces noise exposure', 38% to the statement 'Reducing hours of working in a noisy section prevents HL' and 53% to the statement 'Laws exist to protect workers from being exposed to high noise at work'.

Overall 76% of the participants had a positive attitude to the importance of noise reduction in the workplace, NIHL, audiometry and wearing of hearing protection devices. About 94% of the participants displayed poor practice regarding provision and use of hearing protection devices, health and safety training and audiometry. Most of the participants responded 'Never' to most of the statements. For example, 82% responded 'Never' to the statement 'availability of posters in sections required to wear earplugs/muffs', 95% to the statement 'Workers attend organized training sessions on using hearing protection devices in the workplace' and 91% to the statement 'Workers undergo ear-screening test (audiometry) annually'. In addition, 86% of the participants responded 'Never' to 'Workers provided with hearing protection devices at work', and a similar percentage responded likewise to 'Workers wear hearing protection devices when working in a noisy environment'.

6.0 Discussions

6.1 Main Discussion

We found a higher prevalence of NIHL among workers in iron and steel factories compared to the controls. The workers were exposed to a sound level above the recommended occupational exposure limit values, and they did not use HPDs. This suggests a relationship between the occupational noise exposure and NIHL among iron and steel workers. However, due to the epidemiological design of the study, the causal relationship cannot be confirmed.

The average duration of work for workers in the iron and steel factories was 5 years (range 0-24 years). This average work duration is within the first 10 years-period in which the risk of hearing damage is estimated to be high when the ear is exposed to high noise levels [16, 49, 71]. Although many workers in our study have not worked as much as 10 years. In addition, about 20% of workers had previously worked in noisy jobs and they might have been sufficiently exposed to high sound levels over time which would have increased their risk of NIHL. However, we have no information of the sound levels these workers were previously exposed to.

It has been established in previous literature that occupational noise exposure above 85dB (A) is associated with an increased risk of NIHL among exposed workers and the effect is evident at frequencies of 3,4 and 6 kHz [16, 42, 73, 132, 133]. Below this level, the risk of hearing damage is estimated to be insignificant [134]. In addition, it is estimated that between 22% and 38% of workers exposed to occupational noise of 90 dB(A) and 95dB(A) respectively are likely to develop NIHL with 10 years of exposure or more [6]. In our case, 17% of workers had more than 10 years of exposure and this may partly explain the high prevalence of NIHL in this group. The OEL of 85 dB(A) is used by many countries is the world, and it is considered as a health-based limit, i.e. a maximum sound level that is set to protect workers from hearing damage, although some people may develop NIHL at lower sound levels due to different biological susceptibilities among individuals [42]. Nevertheless, some other countries use different exposure limits, for example India and US-OSHA use 90 dB(A), thus reflecting that decisions of occupational noise exposure limits often do not only consider health aspects, but also technical feasibility in the workplaces, ethical, political and socio-economic status [77, 135].

Age is one of the main factors for the hearing loss. To adjust for age can be difficult in statistical analyses. In this study, we stratified the working population into three age groups and found a borderline increased risk of hearing loss among the younger age group (18–35 years), and significant differences between exposed and controls in hearing thresholds for the frequencies of 4000 and 6000Hz. The significant difference in the dip for the 4000 and 6000 Hz frequencies is a sign indicating hearing loss due to noise exposure in this age stratum [94, 96, 136, 137]. Similar findings have been shown among gold miners in South Africa, where the greatest difference in hearing threshold between age strata was found among the younger age group (16–40 years) at the noise dip of 4000 Hz [47].

In this study we found higher estimates of NIPTS than predicted by ISO 1999 standard for the age group 18–35 years at frequencies of 4000 and 6000 Hz. This supports our findings when we used the control group for comparison. The pattern of NIPTS among our participants was similar to that of ISO 1999. The results suggest the likelihood of NIHL because of the significant effect observed in higher frequencies which are related to the noise exposure [40]. However, the characteristics of noise, size of ear canal and other factors determine the location of notch for the higher frequencies (from 3000-6000 Hz) [41]; the notch at these frequencies, and especially at 4000 Hz, is an established clinical sign and may be valuable in confirming the diagnosis of NIHL [40, 42]. In addition, our NIPTS estimates, though generally lower than those predicted by ISO 1999, show similar patterns, especially at higher frequencies. This result differs from a study conducted in the USA that reported estimates more in agreements with ISO 1999 [43]. The lower results and estimates from our study may be explained partly by differences in the reference population characteristics. The ISO 1999 standard was prepared based on populations from developed and industrialized countries such as the USA and with more continuous noise [30], making it difficult to compare with the results of our study since we encountered a mix of noise characteristics.
Other studies among iron and steel workers also have found an increased prevalence of hearing loss due to high occupational noise (Table 2). For example, a study conducted among Indian iron and steel workers exposed to noise level above 90 dB(A) found that over 90% of the workers engaged in casting and forging had hearing loss in the higher frequencies, i.e. 4000 and 6000 Hz [97]. This is probably caused by tasks and tools that emit high noise level during the steel production process. In addition, noise characteristics and the increased level of factory mechanization may increase the risk of NIHL. A study done in Nigeria also found a higher prevalence in the worse ear (57%) among steel mill workers exposed to 75–93 dB (A), with a pure tone average hearing loss of 30 dB, 31 dB and 32 dB for the finishing, mill floor and

mechanical departments respectively, as compared to a pure tone average of 21 dB among administrative workers with lower noise exposure (49 dB (A)) [96]. In Nepal, the prevalence among workers in a steel factory was comparable to our study, i.e., 40% and 46% for the right and left ear, respectively. However, the Nepalese study excluded workers over 45 years and information on factory characteristics were not available [138]. Another study done in Nepal among 115 small-scale metal industry workers and 123 controls found a lower prevalence for the exposed (30%) and only 4% for the controls [102]. The difference in prevalence between the Nepal study and our study may be partly due to the definition used for hearing loss (Table 2). In addition, the workers in Nepal used ear protection during work [4, 102]. Nevertheless, the high prevalence presented in these studies suggests that noise exposure contributes substantially to hearing loss [53].

The measured hearing loss in our control group was lower than that reported among the controls in South African miners study for the higher test frequencies, i.e. 31% versus 46% respectively [48]. The control group in the South African study was the administration group of the same workplaces, and the control group was not screened for previous noise exposure as we did in our study. The participants in our control group were screened for several factors responsible for hearing loss and were thus expected to have low prevalence. Yet, the prevalence of hearing loss in our control was far higher than the one reported in a community study in Uganda, i.e. the prevalence of hearing loss of 12% [51]. This indicates that there might be factors other than noise that may have contributed to the hearing loss in the South African study. Furthermore, the Ugandan study was conducted in a rural district which is likely to have less noise than urban areas. In Tanzania, there are no published data on community hearing profile among adult. Community studies conducted in other African countries such as Nigeria and Egypt found a lower prevalence of hearing loss (defined as hearing threshold >25dB) than we found, i.e. 18% and 16% respectively [139]. However, in these community studies, there is no information on noise exposure profile among the participants, and this makes it difficult to compare with the control group in our study. Based on the selection of examined workers, our control group can be used in the present study.

Several studies from Africa (Nigeria; 72-93dB(A)) and Asia [China; 85-95dB(A), India; 60-105dB(A), UAE; 70-96dB(A), Iran; ≥85dB(A), and Saudi Arabia; 90.5-95.0dB(A)] have reported comparable high noise levels in iron and steel factories (Table 2). This shows that the working environment in iron and steel factories involves high noise levels that may increase the risk of NIHL. The moulders, one of the job groups, in the Indian study [101], had a higher noise exposure (91 dB(A)) than we found for this job group, i.e. 88 dB(A). The differences in the results may be partly explained by differences in tasks, processes, machines, tools and production technology. Furthermore, the methods and devices used in these studies might have contributed to differences in the recorded noise levels.

In our study, we identified six potential noise exposure determinants, three in each section, i.e. in the furnace and rolling mill section respectively. These determinants were further categorized into task-related determinants (those based on specific job/activity or task assigned to workers) and factory-related determinants (those based on factory layout and or design). Two of the three determinants in the furnace section were task-related, i.e. manual handing of raw materials/ billets/crowbars and billet weighing/transfer and they increased noise exposure by about 2 dB(A)'s each. This was presumably caused by colliding objects in motion, tools and metals when offloading raw materials from vehicles, sorting raw materials/metal scraps, transfer and feeding into the furnace, as well as collisions during manual weighing of steel billets. The factory-related determinant, i.e. furnace installation below the ground floor, reduced the noise exposure by 2 dB(A) probably by reducing the direct sound transmission form the furnace to the workers, suggesting the importance of encompassing noise control considerations in engineering design. In addition, two determinants in the rolling mill section, i.e. the use of large billet weight (100 – 120kgs) and a large cutting machine increased noise by 3 dB(A) and almost 2 dB(A), respectively. This may be due to the heavy weight of the steel billet that might result into high impacts with various machines while in motion during the steel bar production process. In this section, feeding of the re-heating furnace was the only task-related determinant that was observed to reduce noise by 2 dB(A), presumably since this working area is located at the far end of the rolling mill section and is thus less impacted by high noise level from the rest of working areas where noise is emitted by machines and operations. Several other studies in other types of industries have used this approach to identify exposure determinants [140, 141]. Descriptions of such exposure determinants and their contributions to the recorded noise levels provide a basis for planning and implementation of appropriate noise control measures; for example, training workers encouraged to handle metal objects and tools more gently may reduce the noise levels associated with tasks such as weighing of billets and loading the pusher machines. Also, reducing dropping height and/or installation of vibration-absorbent material on surfaces may reduce noise emission from colliding surfaces.

Most workers had a poor knowledge of NIHL. Furthermore, they also had poor practice regarding the use of HPDs, which might not be surprising since the majority of the workers reported non-availability of these devices at their workplaces. Nevertheless, the majority had a positive attitude regarding the importance of noise reduction in the workplace, prevention of NIHL, audiometry and use of HPDs. Low knowledge and poor practice concerning occupational noise and NIHL might be related to the increased prevalence of NIHL. The non-availability of HPDs in the workplace may be due to weak implementation of legislation and follow-ups from governing institutions. A study of Malaysian quarry workers found a similar trend, i.e. a high prevalence of NIHL (57%), with a low level of knowledge (11%) and practice (16%) among workers [119]. In contrast to this, two studies done in Nigeria among steel-mill and textile dye workers respectively found a good level of knowledge of 93% and 74% [121, 142], but a high prevalence of NIHL (57%) [96], indicating that a good level of knowledge may not be sufficient to prevent NIHL, and that the relationship between knowledge and NIHL is not likely to be linear. This might be an interplay of multiple other factors. On the other hand, several studies in Nigeria and Malaysia reported poor practice [119-121, 142]. Although information regarding provision of HPDs for workers in these studies varied, it is likely that non-provision of HPDs by employers at the workplaces was the reason for a low level of utilization of the protective measures, or even non-utilization. Thus, provision of HPDs with education and fit-training in workplaces where workers are exposed to harmful noise is important.

Our findings indicate that the majority of our study participants had a positive attitude towards the importance of noise reduction at the workplace, NIHL, audiometry and wearing of hearing protection devices. Our finding is in line with two studies of Malaysian sawmill and quarry workers, whose attitude scores were 61% and 70% respectively [119, 120] The positive attitude of our study participants may be regarded as an intention to change their behaviour [143] and is probably a good sign for future preventive work.

6.2 Methodological discussion

6.2.1 Study design

Our study consisted of an exposure study and an epidemiological study with cross-sectional design where exposure (occupational noise) and outcome (NIHL) were measured in the same period. This study design reduces the possibility of drawing conclusions regarding the existence of a causal association between occupational noise exposure and the prevalence of NIHL [144, 145]. A longitudinal study design would be an alternative with noise measurements/assessments for a longer period and studies of hearing loss at baseline and follow-up. However, longitudinal study designs are costly and require longer follow-up time [146, 147]. Most longitudinal studies on the incidence of NIHL have been done in other regions (mostly the USA and Europe) and only a few in African countries. Limited studies in Africa raises a question about the external validity of the previous studies, as development of hearing loss is partly influenced by biological susceptibility to noise, inner ear melanin and cochlear melanocytes [47, 148]. Theoretically, it would be of interest to perform longitudinal studies of NIHL in the factories of the present study. However, with the present knowledge about high occupational noise exposure found in these iron and steel factories, it is very likely that workers are at high risk of developing NIHL, and hence it would be unethical to opt for longitudinal studies. Intervention studies would be a better choice. The knowledge gained in the present study which include documentation of the high occupational noise exposure levels and related determinants in iron and steel factories, the high prevalence of NIHL among noise exposed workers and low level of knowledge, poor practice with positive attitude measured in workers, may provide sufficient information for some policy and decision-making regarding noise control interventions in these workplaces.

6.2.2 Study population

Our study participants were randomly selected from a list of the workers provided by their respective management. All workers had equal chances of being selected for the study. We used a table of random numbers to obtain the previously estimated sample size. In so doing, we were able to minimize the possibility of selection bias. Thus, we have no reason to doubt the representativeness of our sample of iron and steel workers. In addition, for Papers I and II, the response rate was 100% and 87% respectively. In the prevalence of NIHL study (Paper II), it was necessary to exclude some participants (32 from the exposed and 16 from the control groups), based on exclusion criteria; those who reported having congenital hearing loss, a history of otitis media during childhood, having worked in noisy jobs only among the controls, and those who reported using long-term medication because the participants did not have adequate knowledge about the type of medication they used. This was done to reduce the potential of contamination (bias) in the outcomes estimates, i.e. the prevalence of NIHL [149].

For the exposure study, workers in the same job group performing similar tasks, processes and using the same tools in the same area were assumed to constitute similar exposure profiles [127]. Consequently, the workers were categorized into a total of 13 exposure groups according to their job (Table 3). Rappaport and Kupper suggested 10–20 measurements in each exposure group, i.e. repeated measurements of 5–10 workers [150, 151]. Thus, we aimed at randomly selecting 5–10 workers from each job group in each factory. However, not all job groups were available in each factory, and when they were available, the total number of workers per job group varied from 2 to 35. All workers were selected if the job group comprised five or fewer workers. This might have resulted in imprecise estimates of the mean occupational noise exposure among those job-groups with a lesser number of workers compared to the ones with a larger number of workers. More repeated personal measurements on different days would probably provide more precise estimates of occupational noise exposure and a better understanding of the patterns (day-to-day), characteristics and determinants for occupational noise exposure. Furthermore, the grouping scheme used in an exposure study was the *a priori* grouping (using existing job groups, tasks and sections). For example, the mean personal noise exposure for cutters/bundlers job-group was 96dB(A) with wide standard deviation of 5dB(A) suggesting existence of variability in noise exposure even within same job group. However, the a *priori* grouping scheme and related exposure data was not used in epidemiological study on the prevalence of NIHL where *a posteriori* grouping scheme (re-grouping based on measured noise exposure levels) would probably have yielded higher contrast in noise exposure.

The control group for the prevalence of NIHL study comprised the public primary school teachers. We assumed from the published studies that this job group is exposed to a low level of occupational noise [49, 152-154]. The 8-hour equivalent noise exposure among these controls at work was 79.7 dB(A). Hence, one would expect an overall lesser prevalence of hearing loss among this group [134]. However, the prevalence of hearing loss in this group (31 %) was higher compared to the prevalence population survey in Uganda (12%) [51] that we previously used for sample size calculation. This suggests that there are likely other contributing factors for this high prevalence, and these warrant more investigation. Using another control group such as data from a population survey might have been an alternative, but such population studies and community baseline data do not exist in Tanzania. Nevertheless, the availability of the control group strengthened our study.

Bias (selection bias and information bias) is explained as any systematic error in the design, conduct, or analysis of a study and may highly affect the study validity. We collected part of the study information using an interview-based questionnaire. Questionnaires are prone to recall and social desirability bias [155]. The contents of the KAP study did not demand much memory, as the information collected was basically from daily work, although some events and tasks such as the provision and the use of HPDs might be better recalled than others, for example, audiometry [155]. To minimize this, the tool we used was validated, and the items used in the KAP domains had high internal consistence assessed by estimating Cronbach's alpha coefficient (α), resulting in α= 0.74, 0.70 and 0.72 for knowledge, attitude and practice domains respectively. [155]. Hence, the study results are presumed to be valid.

The interview of all the participants was conducted privately by the same research personnel who is a Tanzanian and knew the language and culture. Also, the research personnel had prior training, and the objective of the study was clearly explained to each participant [156]. This provided an opportunity for reliable responses. The interviews were performed at the workplace, and the research team was available in the factories during data collection. This was probably beneficial for obtaining correct information from participants since they could have tried to hide problems due to fear that the information would leak to the employer. However, we are not certain of this and have no reason to suspect such thoughts on the part of the participants.

Despite the mentioned potential bias issues, we believe that this study had good internal validity and that the results are reliable.

The four studied iron and steel factories in Tanzania had similarities in characteristics of study participants, re-bar production process, plant technology, job groups, sections and tasks, with some differences. Factory owners (companies) reported having iron and steel factories in other regions of the country and some other sub-Saharan Africa countries with similar structure, characteristics and production technologies. These other iron and steel factories are also likely to have high occupational noise levels, as we measured in our study. Without any intervention, workers are at increased risk of acquiring NIHL over time. This suggests that our study results for occupational noise exposure (Paper I) and the prevalence of NIHL (Paper II) may be representative for the other iron and steel factories in Tanzania and other countries with similar characteristics and production technology, i.e. the study has this type of external validity. However, generalization of the KAP study results must be done with caution because studies use different design methods and scoring or grading criteria, i.e. cut-off points for good and poor scores [112, 117-120].

6.2.3 Noise exposure assessment

In this study, we used two calibrated devices to measure occupational noise exposure, i.e. a hand-held sound level meter (SML) for area measurements and a portable noise dosimeter for personal measurements. Area measurements using the sound level meter have been widely used to indicate workers' noise exposure in regions of limited economic resources including African and Asian countries (Table 2). Some reasons for this may be that the use of SLM is relatively inexpensive; it is easy to conduct, and it takes less time than personal measurements. However, we must acknowledge not only the strength and applicability but also the weaknesses of these instruments [30]. The mean personal noise measurement was higher compared to the area measurements, i.e. 92.0 vs. 90.5 dB(A). One explanation might be that the area noise level corresponding to the work area for a job group was based on the unweighted mean of several points of measurements, while the worker within the job group could have spent more time in subareas with higher noise levels than the estimated mean area noise level. However, we did not track the movements of the workers to confirm this. Other studies in different workplaces have found an analogous difference between personal and area noise measurements, for example in an iron and steel factory in India (130 vs. 105 dB(A)) [97], in Swedish pulp mills ((85.1 vs. 83.6 dB(A)) [107] and in a Norwegian Navy study (a difference of > 10 dB(A) among personnel aboard frigates and Coast guard vessels) [19]. Thus, area measurements may underestimate the actual noise exposure among workers, suggesting that a conservative approach should be taken in using area measurements in risk assessment related to hearing loss.

The personal noise measurements were performed over several days, with repeated measurements using high quality instruments following the ISO 9612:2009 standard, and this must be considered a strength of this study. More detailed assessment of tasks performed might have improved the noise exposure models by explaining parts of the within-worker variability. On the other hand, the area noise measurement was done in only one day in each factory. However, the area measurements were assumed to be performed during stable working condition and should be representative for the work tasks done at the time. Our descriptions of factory buildings, noise sources and the measured workers' noise exposure are important inputs in noise control measures [79].

Some of the variability in the individual measurement might be due to mechanical contact with the microphone during work [19]. We were present in the factory during the sampling period and we did not record any of this event. Although we cannot ignore the possibility of it having occurred, its contribution should have a minimal impact on the overall results when taking into account the generally high noise levels in the factories. Furthermore, the factory production rate during noise measurements was stable and thus representative of normal working condition in iron and steel factories.

6.2.4 Audiometry (Pure Tone Audiometry)

We used a factory pre-calibrated, gold standard manual PTA for all participants in the study [129]. Measurements were conducted by trained personnel following the same test procedure and protocol for all study participants. These measures minimized the occurrence of measurement error. The participants were instructed to avoid areas with a high level of noise for a minimum of 12 hours prior to audiometric examinations to minimize the possibility of temporary threshold shift (TTS) [6, 23, 129]. This means workers scheduled for examination left their workplace earlier than normal. The duration since last occupational noise exposure (free noise exposure) was recorded before the audiometric test was administered. Other studies used a varied minimum time of 16 hours or more before audiometry for exclusion of possible contribution of TTS to permanent threshold shift [157-160] however, the validity for these variations (minimum of 12, 16, 24 or more resting time after noise exposure) need more investigations for humans. Given the occupational noise exposure variability in our study, more resting time probably would be an alternative option but would have been practically difficult [159] as more working hours would have had to be sacrificed while waiting for audiometry. Furthermore, although measurements were done in a locally constructed booth within a quiet room, monitoring of background noise in the booth using a calibrated portable hand-held SLM showed that all measurements were in conformity with ISO 8253 standard. For best results, audiometry was conducted in the morning before any work exposure. In addition, the city is less noisy in the morning compared to other times of the day when the participants could potentially be exposed to a higher level of environmental noise.

In many societies today, people listen to music at high volume levels, and this may affect their hearing ability. We have limited information about leisure time exposure to noise among our study participants, but we have no reason to believe that the workers in iron and steel factories are more exposed to leisure time sound than are the control workers. In future studies, monitoring of leisure time exposure should be performed.

6.2.5 Questionnaire

Deterioration of humans' hearing ability might also be related to other risk factors apart from exposure to noise and the age, which we have discussed above. Such factors are current smoking, exposure to organic solvents, use of ototoxic medicines, vibration, genetics, head and ear injury, ear infections and illnesses. These risk factors need to be controlled for when analysing to ascertain the association between noise exposure and NIHL. In this study, we used an interview-based questionnaire to collect information about these variables. We then used statistical analyses to control for confounding effect. In addition, we used information collected through a structured interview with both exposed participants and controls to exclude those with congenital hearing loss (one participant), six with history of otitis media during childhood and two among the controls who reported to have worked in a noisy job. In addition, we excluded four participants who reported using long-term medication because the participants did not have adequate knowledge of the type of medication they used. Through this process, one might not ignore the effect of residual confounding [161, 162].

Language differences in questionnaire may have consequences, because concepts in one language may be understood differently in another language. Hence, in research, language translation involves interpretation [163]. In addition, during translation, the items must retain the intended meaning and measurement properties of the source questionnaire while accommodating the local culture and language. The English version of the validated questionnaire was translated into Swahili and then back to English for logical consistency and meaning, then shared among experts of the research team. The word 'deafness' was translated into ‘hearing loss’ reflecting the contextual area for the research [164]. The final version was used for pre-testing and training the research assistant who then administered the interview. This ensured consistency and familiarity with each term used in the questionnaire. Furthermore, to collect information for the KAP study, interview-based questionnaire was used as a preferred tool over self-administered questionnaire [165, 166].

7.0 Conclusions

The findings in our study show that workers in the iron and steel factories were exposed to noise levels above OEL of 85 dB (A) and that they did not use HPDs. This may increase the risk of developing NIHL. In the furnace section, three determinants of noise exposure were significant: furnace installation, billet weighing/transfer, and manual handling of raw materials/billets/crowbars. In addition, three determinants (the size of the cutting machine, steel billet weight and feeding re-heating furnace) were significant in the rolling mills section.

We also, found a higher prevalence of hearing loss among iron and steel factory workers exposed to noise than among the controls, i.e. 48% vs. 31% respectively. In addition, a comparison of hearing thresholds between the two groups for the frequencies sensitive to noise, i.e. 4000 and 6000Hz, revealed significant differences.

Most workers in the studied iron and steel factories had a poor knowledge of NIHL, as well as poor practice regarding provision and use of hearing protection devices, health and safety training. However, they had a positive attitude to the importance of noise reduction at the workplace, NIHL, audiometry and wearing of hearing protection devices which is a potential attribute towards successful HCP.

8.0 Recommendations

8.1 Workers in the factories who participated in the present study should be provided with HPDs with proper fit-training and education on why and how to use HPDs.

8.2 Efforts should be made to reduce occupational noise levels to acceptable limits by addressing the determinants for noise exposure. Noise assessment should be carried out after improvements have been made to confirm reduced sound levels.

8.3 In Tanzania, it would be appropriate to establish and or strengthen a functioning workplace surveillance and monitoring system for noise levels and hearing.

9.0 Future Research Perspectives

9.1 Interventional studies on various noise control measures including the use of HPDs. Evaluation on effectiveness of such interventional programmes is necessary component of research.

9.2 Occupational noise and NIHL awareness programmes, workers training on task-based noise determinants may provide useful knowledge for effectiveness studies targeting noise reduction and prevention of development of NIHL.

9.3 Noise assessment using task-based strategy may provide detailed knowledge on noise reduction in iron and steel factories

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ANNEX I: Information letter & Request for participation in a research project
Title: Noise exposure and Hearing Loss among iron and steel workers in Tanzania

Principal Investigator: Israel P. Nyarubeli

Institution Address: *University of Bergen, Department of Global Public Health and Primary Care, Centre for International Health; N-5020, Bergen; Norway*

Background and purpose

This is a request for you to participate in a research study that intends to obtain knowledge on noise exposure levels and hearing loss among iron and steel workers in Tanzania. You have been randomly selected to participate as one of representative of workers in the factory. For being sure that you are informed about participating in the research, we are asking you to read this consent form. You will also be asked to sign it (or make your mark). Before contacting you, we have obtained a permission to conduct this study from the Factory authority.

What does the study entail?

The study will involve measuring of noise levels from workplaces, measurement of personal noise exposure levels, interviews, ear examinations and audiometric tests. We will ask you some questions related to personal information and with regards to your occupation. Some of you will be asked to wear personal noise sampling equipment for the whole day shift and interviews on tasks performed during working shift will be done and you will undergo ear examination. Please feel free to Participate

Potential advantages and disadvantages

This study will generate knowledge on occupational noise exposure levels and establish the magnitude of hearing loss among workers. This information will be useful in improving working condition in factories and policy making at National level. You will have chance to know your hearing status and the level of noise you are working with. You might expect immediate changes of working environment after the project, however, we cannot guarantee that the employer will follow any recommendation on this matter. This study is not expected to harm its participants.

What will happen to the samples and the information about you?

The data that are registered about you will only be used in accordance with the purpose of the study as described above. All the data and samples will be processed without name, ID number or other directly recognisable type of information. A code number links you to your data through a list of names. Only authorised project personnel will have access to the list of names and be able to identify you. It will not be possible to identify you in the results of the study when these are published.

Voluntary participation

Participation in the study is voluntary. You can withdraw your consent to participate in the study at any time and without stating any particular reason. This will not have any consequences for your further treatment. If you wish to participate, sign the declaration of consent on the final page. If you agree to participate at this time, you may later withdraw your consent without your treatment being affected in any way. If you later wish to withdraw your consent or have questions concerning the study, you may contact **Prof. Mainen J. Moshi,** Chairman of the Senate Research and Publications Committee**, P.O. BOX 65001, Dar es Salaam (Tel 2150302-6, 2152489)** or **Dr. Alexander Tungu, MUHAS, P.O. BOX 65015, Dar es Salaam (Tel 0713170409)** who is one of supervisors for this research**.**

Further information on the study can be found in Chapter A – *Further elaboration of what the study entails.*

The declaration of consent follows Chapter B.

Chapter A – Further elaboration of what the study entails

- Criteria for participation: The study participants will be workers in iron and steel industries working in noisy environment. Exclusion criteria will include; For audiometry; workers with ear surgery or confirmed hearing loss from congenital or any other diagnosis.
- Hearing loss due to noise exposure is a public health problem and commonly reported illness among workers exposed to noisy environment. Workplace exposure to high noise levels above 85dB Time Weighted Average is associated with increased risk of hearing loss. This problem is likely to be higher in developing countries including Tanzania where the economic growth agenda have attracted industrial investments and significant number of workers are employed. However, no documentation has been made on levels of noise workers are exposed to and the magnitude of hearing loss in industrial sector. Also, it is not clear whether workers are aware of the health effects relating to their working environment. This creates a threat towards preventive measures to health and safety of workers in this sector. This study is designed to gather such useful information for policy and preventive services.
- 253 workers from four iron and steel industries will be invited to participate in the study. They will be interviewed, and audiometric test will be done. In addition, 163 workers will be requested to wear portable sampling devices (dosimeter) for full shift. Also, area noise sampling will be done using specialized equipment.
- Potential advantages: The information gathered may be used by respective industry for improvement of workplace environment, participants will have an opportunity to know their hearing status, policy makers may use this information as an input when making country policy and scientific world will have the knowledge regarding noise and hearing loss through international conferences and publications.
- Potential adverse events: The study is not expected to have any harm to participants
- Potential discomfort or disadvantages: Screening for hearing loss is a normal practice conducted under strictly confidential rule between an employee and research team and the procedure is non-invasive for participants, thus it is not expected to cause any discomfort. Portable sampling device (dosimeter) is a small device that does not even reduce efficiency of work and does not add any significant weight to a research participant, thus, it is not expected to cause any discomfort.

- Study participants’ responsibility: It will be the responsibility of study participants to wear and keep sampling device at the sampling position up the end of sampling period. During audiometry, it will be a responsibility of study participants to observe and follow instructions provided. Also, they will be obliged to provide correct information to the best of their understandings during interview.
- The study participants will be informed as soon as possible in case new information becomes available that might influence their willingness to participate.
- There will be no any compensation events. Only transport will be provided where there is no suitable room to accommodate audiometric test.

Consent for participation in the study

Title of study: Noise exposure levels and hearing loss among iron and steel workers in Tanzania

I am willing to participate in the study.

(Signed by the project participant, date)

I confirm that I have given information about the study.

(Signed, researcher, date)

ANNEX IIa: Field data collection tool- Interview based questionnaire (in Swahili)

DODOSO/hojaji juu ya kiwango cha kelele na upotevu wa uwezo wa kusikia (uziwi) miongoni mwa wafanyakazi wa viwanda vya nondo na chuma Tanzania.

Namba ya utambulisho ya kiwanda: ……………….

Namba ya utambulisho ya mashiriki: ………………Tarehe ya hojaji: ....

Maelekezo

i. Tafadhali zungushia namba ya chaguo sahihi

ii. Andika jibu sahihi katika nafasi iliyo wazi: Mfano, umri katika miaka.

A: Taarifa Binafsi		
Na.	**Taarifa hitajika**	**Jibu**
A.1	Umri (katika miaka)	
A.2	Jinsi	1= Me 2= Ke
A.3	Hali ya ndoa	1= Sijaoa 2= nimeoa/kuolewa 3= tengana
A.4	Kiwango cha elimu	1= sikusoma 2= elimu ya msingi 3= elimu ya sekondari 4= elimu ya juu/ufundi/chuo
A.5	Sehemu afanyayo kazi kiwandani (idara/kitengo)	
A.6	Masaa ya kazi/siku	
A.7	Aina ya ajira	1= kudumu 2= muda/kibarua
A.8	Umri kazini	
B: Mazingira ya kazi na Viashiria hatarishi vya upotevu wa uwezo wa kusikia		
Na	**Taarifa hitajika**	**Jibu**
B.1a	Je ni mara ngapi unafanya kazi katika mazingira yenye kelele kubwa kazini?	1= Hapana 2= mara chache 3 = mara zote
B.1b	Kama jibu ni 2 na 3 kwenye swali no. B.1a hapo juu; Je ni mara ngapi unalazimika kupaza sauti kumfanya aliye jirani yako umbali wa urefu wa mkono kukusikia?	1= Hapana 2= mara chache 3 = mara zote
B.2	Uliwahi kufanya kazi katika mazingira ya kelele kabla ya ajira hii? Kama 'ndiyo' tafadhali taja; Jina la kazi …………………………………… Mahali ………………………………………. Shughuli ulizofanya…………………………… Muda uliofanya kazi hiyo ……………………..	1= ndiyo 2= hapana
B.3	Je unatumia/ulitumia vifaa ya kuzuia kelele masikioni unapofanya/ulipofanya kazi katika mazingira ya kelele nyingi?	1= Ndiyo, mara zote 2= mara chache 3= hapana 4= hakuna kelele
B.4	Je umewahi kuwa katika mazingira yenye kelele kubwa kwa mara moja au mlipuko;	1= ndiyo

	i. Kazini? Kama jibu ni 'ndiyo' mara ngapi? ii. Nje ya kazi? Kama jibu ni 'ndiyo' mara ngapi?	2= hapana Mara ……. 1= ndiyo 2= hapana Mara …….
B.5	Je ni mara ngapi hufanya kazi katika mazingira ambayo kemikali hutumika?	1= mara zote (kila siku) 2= mara chache (1 au 2/wiki) 3= kwa nadra sana 4= hapana
B.6	Uliwahi kufanya kazi katika mazingira ya kemikali kabla ya kazi hii?	1= ndiyo 2= hapana
B.7	Kama 'ndiyo' kwa swali no. B.6, tafadhali taja; Jina la kazi …………………………………… Mahali ……………………………………. Shughuli ulizofanya…………………………… Muda uliofanya kazi hiyo ……………………..	
B.8	Je uliwahi kuambiwa na daktari wakati wa uchunguzi kuwa una ugonjwa ufuatao? i. Kisukari ii. Shinikizo la damu iii. Matatizo ya usikivu utotoni (miaka 0 – 17) iv. Matatizo ya usikivu ukubwani	 1= ndiyo 2= hapana 3= sijui 1= ndiyo 2= hapana 3= sijui 1= ndiyo 2= hapana 3= sijui 1= ndiyo 2= hapana 3= sijui
B.9	Je huwa una tatizo la kusikia kelele mfululizo masikioni? Kama ni 'ndiyo' , je huwa unapata usumbufu wowote?	1= ndiyo 2= hapana 1= hapana 2= husumbuliwa kidogo 3= husumbuliwa sana
B.10	Je uliwahi kupata ugonjwa au matatizo yoyote ya masikio? Kama ni 'ndiyo', tafadhali taja ugonjwa au tatizo ulilowahi kulipata	1= ndiyo 2= hapana ……………………………….
B.11	Je uliwahi kuumia au kupata ajali iliyopelekea jeraha ndani ya sikio?	1= ndiyo 2= hapana
B.12	Je unaamini una tatizo la usikivu?	1= ndiyo 2= hapana
B.13	Je kuna ndugu au jamaa yako wa damu aliwahi kuwa au ana tatizo la usikivu?	1= mama (Ndiyo/hapana) 2= baba (ndiyo/hapana) 3= ndugu wa damu (ndiyo/hapana) 4= watoto (ndiyo/hapana) 5= hakuna

B.14	Je uliwahi au unavuta sigara?	1= ndiyo, kila siku 2= mara chache 3= nishaacha 4= hapana
B.15	Kama ni ’ndiyo’ kwa swali no. 14; Tafadhali taja idadi ya miaka uliyovuta Tafadhali taja idadi ya sigara kwa siku	Miaka ………. Idadi ya sigara/siku ………
B.16	Je huwa unakunywa pombe/kileo? Kama ‘ndiyo’ tafadhali taja i. Aina ya kileo unachotumia ………………………………… Idadi ya chupa/glass/makopo utumiayo kwa wiki …………………………	1= ndiyo 2= hapana
B.17	Je uliwahi kuwa katika matibabu ya madawa kwa muda mrefu? Kama ‘ndiyo’ tafadhali taja jina la madawa au tatizo ulilokuwa unatibiwa kwalo? Jina la madawa ………………………….AU Tatizo/ugonjwa ………………………	1= ndiyo 2= hapana
B.18	Je huwa unajishughulisha na shughuli zingine au kuwa katika maeneo ya kelele baada ya kazi hii?	1= ndiyo 2= hapana
B.19	Kama ‘ndiyo’ kwa swali no. 18, tafadhali taja; Kazi …………………………………. Kumbi za starehe au bar ………… Kusikiliza muziki kwa sauti kubwa …………… Nyinginezo (taja) ……………………………	
B.20	Je kuna shughuli au mashine inayotoa kelele kubwa nyumbani au jirani na makazi yako? Kama ‘ndiyo’ tafadhali taja; i. Gereji ii. Mashine ya kusaga au mashine yoyote iii. Generator iv. Bar au club v. Nyinginezo, taja	1= ndiyo 2= hapana

C. Maarifa

Tafadhali soma sentensi zifuatazo na kwa kila moja zungushia **‘ndiyo’** *kama unadhani ni sahihi,* **‘hapana’** *kama unadhani si sahihi, na ‘***sifahamu’** *endapo huna uhakika na jibu lako.*

Na	**Taarifa hitajika**	**Jibu**	**Alama**
C.1	Je uliwahi kusikia kuwepo kwa uziwi unaosababishwa na kufanya kazi mazingira yenye kelele?	1= ndiyo 2=hapana 3= sifahamu	
C.2	Uziwi unaosababishwa na kelele hautibiki	1= ndiyo 2=hapana 3= sifahamu	

C.3	Uziwi hutokea endapo mfanyakazi anafanya kazi katika mazingira ya kelele	1= ndiyo 2=hapana 3= sifahamu	
C.4	Uziwi unaweza kutokea endapo mtu atakuwa kwenye matukio yenye kelele nyingi kama mlio wa risasi au kugongana kwa vitu vyenye nyuso ngumu	1= ndiyo 2=hapana 3= sifahamu	
C.5	Hatari ya uziwi inaweza kuongezeka endapo mtu atatumia kileo na huku akifanya kazi katika mazingira yenye kelele	1= ndiyo 2=hapana 3= sifahamu	
C.6	Matumizi ya baadhi ya madawa yanaweza kusababisha uziwi	1= ndiyo 2=hapana 3= sifahamu	
C.7	Baadhi ya mambo mtu apendayo kama kuogelea kwenye kina kirefu na kusikiliza muziki kwa sauti ya juu vinaweza kusababisha uziwi	1= ndiyo 2=hapana 3= sifahamu	
C.8	Hatari ya uziwi inaweza kuongezeka endapo mtu atavuta sigara/tumbaku na huku akifanya kazi mazingira yenye kelele	1= ndiyo 2=hapana 3= sifahamu	
C.9	Maambizi ya sikio yanaweza sababisha uziwi	1= ndiyo 2=hapana 3= sifahamu	
C.10	Usaha sikioni ni dalili za awali za uziwi unaosababishwa na kelele	1= ndiyo 2=hapana 3= sifahamu	
C.11	Kutoweza kutambua sauti ya maongezi ni dalili ya uziwi	1= ndiyo 2=hapana 3= sifahamu	
C.12	Kusikia kelele masikioni ni dalili ya uziwi	1= ndiyo 2=hapana 3= sifahamu	
C.13	Uziwi unaweza kutibiwa kwa madawa	1= ndiyo 2=hapana 3= sifahamu	
C.14	Kuacha kufanya kazi mazingira ya kelele kunaweza kusababisha kupona kabisa kwa mtu mwenye uziwi	1= ndiyo 2=hapana 3= sifahamu	
C.15	Uziwi mahali pa kazi unaweza kuzuiwa kwa kuvaa vizuia kelele masikioni	1= ndiyo 2=hapana 3= sifahamu	
C.16	Uziwi mahali pa kazi unaweza kuzuiwa kwa kupunguza masaa ya kufanya kazi kwenye vitengo vyenye kelele	1= ndiyo 2=hapana 3= sifahamu	
C.17	Uziwi mahali pa kazi unaweza kuzuiwa kwa kuweka vizuia kelele kwenye mashine zinazotoa kelele.	1= ndiyo 2=hapana 3= sifahamu	
C.18	Kuna sharia na kanuni zinazo wakinga wafanyakazi kutofanya kazi maeneo yenye kelele	1= ndiyo 2=hapana 3= sifahamu	

D: Mtazamo

Tafadhali soma sentensi zifuatazo, kisha zungusia **'nakubaliana sana'** *au* **'nakubali'** *kwa sentensi sahihi kulingana na uzito wake,* **'sikubaliani'** *au* **'sikubaliani kabisa'** *kwa sentensi isiyo sahihi, na* **'wala sikubali ama sikatai'** *endapo huna msimamo wowote.*

Namba	Taarifa hitajika	Jibu	Alama
D.1	Sifanyi kazi katika mazingira ya kelele inayoweza sababisha uziwi	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai 2= sikubaliani 1= sikubaliani kabisa	
D.2	Naamini kufanya kazi katika mazingira ya kelele kwa ‘shift’ moja kwa siku hakuwezi kusababisha uziwi	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai 2= sikubaliani 1= sikubaliani kabisa	
D.3	Nadhani uziwi husababisha na vitu vingine kama uzee, jeraha sikioni na kufanya kazi katika mazingira ya kelele	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai 2= sikubaliani 1= sikubaliani kabisa	
D.4	Nahisi, sipaswi kujipa taabu juu ya kiwango cha juu cha kelele ili mradi nina nguvu na mwenye afya njema	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai 2= sikubaliani 1= sikubaliani kabisa	
D.5	Naamini, naweza kupata tiba kutoka kwa mganga wa jadi nikipatwa na uziwi	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai 2= sikubaliani 1= sikubaliani kabisa	
D.6	Nadhani, uchunguzi wa masikio siyo wa muhimu katika mahali pangu pa kazi	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai 2= sikubaliani 1= sikubaliani kabisa	
D.7	Nahisi, mwajili wangu anapaswa kujulishwa endapo nitapatwa uziwi	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai 2= sikubaliani 1= sikubaliani kabisa	
D.8	Nahisi, ni wajibu wetu wote kupunguza kiwango cha kelele mahali pa kazi	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai 2= sikubaliani 1= sikubaliani kabisa	
D.9	Nahisi, si wajibu wangu kuvaa vizuia kelele masikioni nikiwa nafanya kazi sehenu zenye kiwango kikubwa cha kelele	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai 2= sikubaliani 1= sikubaliani kabisa	
D.10	Kwa maoni yangu, siyo muhimu sana kuwa na sheria za kupunguza kiwango cha kelele mahali pa kazi	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai 2= sikubaliani 1= sikubaliani kabisa	
D.11	Nahisi, kuvaa vizuia kelele masikioni wakati nafanya kazi ni mzigo na unanifanya nisiwe huru kufanya kazi vizuri	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai 2= sikubaliani 1= sikubaliani kabisa	
D.12	Nadhani, naweza kutumia vizuia kelele masikioni vizuri kabisa bila ya kupata mafunzo yoyote	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai	

		2= sikubaliani 1= sikubaliani kabisa	
D.13	Kwa maoni yangu, mwajili anapaswa kunilipa fidia endapo nitapatwa na uziwi kwa shughuli niifanyayo.	5= nakubaliana sana 4= nakubaliana 3= wala sikubali ama sikatai 2= sikubaliani 1= sikubaliani kabisa	

E. Vitendo

Zifuatazo ni sentensi zinazohusu maisha ya kazi ya kila siku, tafadhali toa jibu sahihi kwa kila sentensi juu ya kile kifanyikacho kila siku kwa kuzungushia **'hapana'** *kama kitendo hakifanyiki,* **'mara chache'** *endapo kitendo hiki hufanyika kwa nadra,* **'mara zote'** *endapo kitendo hufanyika siku zote.*

Namba	Taarifa hitajika	Jibu	Alama
E.1	Kuna mabango sehemu zote ninazohitajika kuvaa vizuia kelele masikioni	1= hapana 2= mara chache 3= mara zote	
E.2	Nimepewa vizuia kelele masikioni vilivyothibitishwa kutumika mahali pangu pa kazi	1= hapana 2= mara chache 3= mara zote	
E.3	Huwa nanunua vizuia kelele masikioni kwa ajili ya kazi yangu	1= hapana 2= mara chache 3= mara zote	
E.4	Huwa nahudhuria mafunzo yaliyoandaliwa juu ya namna ya kutumia vizuia kelele masikioni mahali pangu pa kazi	1= hapana 2= mara chache 3= mara zote	
E.5	Huwa natumia vizuia kelele masikioni kipindi nifanyapo kazi kwenye kelele nyingi	1= hapana 2= mara chache 3= mara zote	
E.6	Huwa namuarifu msimamizi wangu pindi kizuia kelele masikioni changu kikipata hitirafu au kuharibika	1= hapana 2= mara chache 3= mara zote	
E.7	Huwa nahifadhi kizuia kelele mazikioni changu nyumbani kwa sababu za kiusalama	1= hapana 2= mara chache 3= mara zote	
E.8	Huwa hahifadhi vifaa vyangu vya kuzuia kelele katika mahali maalumu hapa kazini	1= hapana 2= mara chache 3= mara zote	
E.9	Huwa Napata taarifa kutoka kwa kamati ya afya na usalama kazini juu ya kujikinga na kiwango kikubwa cha kelele	1= hapana 2= mara chache 3= mara zote	
E.10	Huwa nafanyiwa uchunguzi wa masikio kila mwaka ili kufahamu hali halisi ya usikivu wa masikio yangu	1= hapana 2= mara chache 3= mara zote	
E.11	Huwa namwonesha mwajiri wangu majibu yangu ya usikivu yakitoka	1= hapana 2= mara chache 3= mara zote	
E.12	Huwa nawaonesha kamati ya afya na usalama kazini majibu yangu ya usikivu yakitoka	1= hapana 2= mara chache 3= mara zote	

ANNEX IIb: Field data collection tool- Interview based questionnaire (in English)

Title: Noise exposure levels and Hearing Loss among iron and steel workers in Tanzania

Factory Identification: ……………………………………….

Participant identification: .... **Date of Interview**: ....

Instructions

i. Please circle the correct number in given options

ii. Write a correct number in spaces provided for example age in years

A: Socio - Demographics		
Qn. no	**Information needed**	**Response**
A.1	Age (in years)	
A.2	Sex	1= Male 2= Female
A.3	Highest level of education	1= No formal education 2= Primary education 3= Secondary education 4= Tertiary
A.4	Working section	
A.5	Main task(s)	
A.6	Working hours/day	
A.7	Type of employment	1= permanent 2= casual/temporary
A.8	Duration of employment in this work	
B: Work, Noise exposure and risk factors		
Qn. no	**Information needed**	**Response**
B.1a	How often are you exposed to high noise levels at your work?	1= No, never 2= Sometimes 3= Always
B.2b	If the answer is 2, and 3 in question B.1 above, How often did you have to raise your voice to make yourself heard by someone an arm's length away from because of noise at work?	1= No, never 2= Sometimes 3= Always
B.2	Have you worked in noisy job before this job? If 'Yes' please specify Name of job………………………………. Place ………………………………………. Task ………………………………………. Years worked ……………………………	
B.3	Do you/Have you used hearing protective devices (e.g. earmuffs, earplugs) at work in noisy areas?	1= Yes, always 2= Sometimes 3= No 4= Not applicable (No noise)

B.4	Have you ever been exposed to impulse noise (sudden very loud noises or blast) without using hearing protective devices the last 12 months? i) At work? If 'Yes' how many times? ii) Outside work? If 'Yes' how many times?	1=Yes 2=No Number exposed ………………………. 1=Yes 2=No Number exposed ……………………….
B.5	How often do you have to work where you use chemicals/organic solvents?	1= Always (daily) 2= Sometimes (1 or 2 times a week) 3= Very rare 4= Never
B.6	Have you ever been exposed to chemicals/organic solvents in any other work?	1= Yes 2= No
B.7	If 'yes' to qn 6 above, please specify; Name of job …………………………………… Place ……………………………………………. Tasks …………………………………………… Years worked …………………………………..	
B.8	Have you ever diagnosed of any of the following conditions? v. Diabetes vi. Hypertension vii. Transient hearing conditions e.g. otitis during childhood (0- 17 yrs? viii. Have you had reduced hearing conditions e.g. otitis during adulthood?	1= Yes 2= No 3= Don't know (never checked) 1= Yes 2= No 3= Don't know (never checked) 1= Yes 2= No 3= Don't know (never checked) 1= Yes 2= No 3= Don't know (never checked)
B.9	Do you have tinnitus (constant ringing in the ear)? If 'Yes' how bothered are you?	1= Yes 2= No 1= not bothered 2= a bit bothered 3= highly bothered
B.10	Have you had other ear disease/injury? If 'Yes' can you please tell us the disease/condition/injury?	1= Yes 2= No …………………………………………

B.11	Have you had temporary reduced hearing, or ringing in the ears after been exposed to noise the last 12 months? i) At work? If 'Yes' how many times? ii) Outside work? If 'Yes' how many times?	1=Yes 2=No Number ………………………. 1=Yes 2=No Number ……………………….
B.12	Have you ever had any trauma or accidents that resulted into head injury?	1=Yes 2=No
B.13	Do you believe you have a hearing loss?	1=Yes 2=No
B.14	Did or does any of your close relatives have reduced hearing?	1= Mother (Yes/No) 2= Father (Yes/No) 3= Siblings (Yes/No) 4= Children(Yes/No) 5= No close relative
B.15	Do you, or have you ever smoked cigarettes?	1= Yes, daily 2= Sometimes 3= Previously 4= Never
B.16	If 'yes' to qn 15 above, for how many years If 'yes' how many cigarettes do you smoke/day?	…………………….. years Number/day ………………….
B.17	Do you drink alcohol? If 'yes' please provide us with the following information. ii. type of alcohol you usually drink iii. number of cans/glasses/bottles per week	1=Yes 2=No type …………………………………. Number/week ……………………….
B.18	Have you ever been into long term medications? If 'yes' please state name of medicine or what condition is (was) it for?	1=Yes 2=No Medicine name(s) …………………… ………………………………………. ………………………………………… Condition it is meant to ………………. ………………………………………..
B.19	Are you engaged in any other jobs and or leisure activities with high noise exposure (e.g. play in a band, attending concerts, hunting with guns, discotheque, others)?	1=Yes 2=No
B.20	If 'yes' to qn 19 above, please specify if; Part time job? …………………………………. Joining leisure places (bars, clubs ets) ………… Listening to music with loud volume …………… Any other ……………………………………	
B.21	Are there activities and or machines that generate noise at or just close to your home?	1=Yes 2=No

	If ‘yes’ please mention them i) Garage …………………. ii) Milling or any other machine ……. iii) Generators ……………………… iv) Bar or club ……………………. v) Any other (specify) …………….	

C. Knowledge *Please read the following statements and for each circle* **‘yes’** *if you think it is correct, circle* **‘no’** *if you think it is not correct and ‘***don’t know’** *if you are not sure or you don’t know the answer.*			
Qn. No	**Information needed**	**Response**	**Score**
C.1	Have you ever heard of hearing loss due to noise exposure?	1= yes 2=no 3= Don’t know	
C.2	Hearing loss due to noise exposure is permanent	1= yes 2=no 3= Don’t know	
C.3	HL may occur if an individual is exposed to noisy environment	1= yes 2=no 3= Don’t know	
C.4	HL may occur if an individual is exposed to events of high noise such as gun fire or impact between two hard surfaces	1= yes 2=no 3= Don’t know	
C.5	The risk of HL may be higher if an individual drinks alcohol and works in noisy environment	1= yes 2=no 3= Don’t know	
C.6	The use of some medicines is likely to cause HL	1= yes 2=no 3= Don’t know	
C.7	Hobbies like diving and listening to louder music for long time may cause hearing loss	1= yes 2=no 3= Don’t know	
C.8	The risk of HL may be higher if an individual smoke and works in noisy environment	1= yes 2=no 3= Don’t know	
C.9	Ear infections can cause HL	1= yes 2=no 3= Don’t know	
C.10	Ear discharge is a sign of HL due to noise exposure	1= yes 2=no 3= Don’t know	
C.11	Poor hearing of normal speech is the sign of HL	1= yes 2=no 3= Don’t know	
C.12	Ringing in the ear is the sign of HL	1= yes 2=no 3= Don’t know	
C.13	HL due to noise exposure can be treated by using medicines	1= yes 2=no	

		3= Don't know	
C.14	Stopping working in high noise level may result into complete recovery or cure when you have acquired HL	1= yes 2=no 3= Don't know	
C.15	HL due to noise exposure can be prevented by workers wearing earplugs and ear muffs	1= yes 2=no 3= Don't know	
C.16	HL due to noise exposure can be prevented by reducing hours of working in noisy sections	1= yes 2=no 3= Don't know	
C.17	HL due to noise exposure can be prevented by encapsulating the noisy generating machines	1= yes 2=no 3= Don't know	
C.18	There is a law and regulation to protect workers from being exposed to high noise levels at workplace	1= yes 2=no 3= Don't know	

D: Attitude

Please read the following statements, circle ***'strongly agree'*** *or* **'agree'** *for correct statement,* **'disagree'** *or* ***'strongly disagree'*** *for incorrect statement and* **'neither agree nor disagree'** *when you are indifferent.*

Qn. No	**Information needed**	**Response**	**Score**
D.1	I don't work in noise level that may harm my hearing	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree 1= strongly disagree	
D.2	I believe working in a noisy environment for one shift in a day does not cause HL	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree 1= strongly disagree	
D.3	I think HL is due to other factors such as age, ear injury and not due to noise exposure	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree 1= strongly disagree	
D.4	I feel, I should not bother on high noise levels as long as I am energetic and healthy	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree 1= strongly disagree	
D.5	I believe, I can consult traditional healer when I have HL	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree 1= strongly disagree	
D.6	I think ear screening program (audiometry) is not so important in my workplace	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree	

		1= strongly disagree	
D.7	I feel my employer should be informed if I have HL	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree 1= strongly disagree	
D.8	I feel it is our shared responsibility to reduce workplace noise exposure	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree 1= strongly disagree	
D.9	I feel wearing hearing protective devices in high noise levels is not my sore responsibility	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree 1= strongly disagree	
D.10	In my opinion, it is not important to have regulations on noise control at my site	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree 1= strongly disagree	
D.11	I feel wearing hearing protective devices during work is burden and uncomfortable	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree 1= strongly disagree	
D.12	I think, I can use hearing protective devices effectively without any training	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree 1= strongly disagree	
D.13	In my opinion, my employer should compensate me if I have HL from this work am doing	5= strongly agree 4= agree 3= neither agree nor disagree 2= disagree 1= strongly disagree	

E. Practice

The following statements relate to daily works, please respond to each statement according to what is always done at your workplace. Circle **'never'** *if you don't practice,* **'sometimes'** *is you do it occasionally, and* **'always'** *if you normally do it.*

Qn. No	**Information needed**	**Response**	**Score**
E.1	There are posters in sections required to wear earplugs/muffs	1= never 2= sometimes 3= always	
E.2	I am provided with approved ear plugs/muffs at my workplace	1= never 2= sometimes 3= always	
E.3	I buy earplugs/muffs for use in my working section	1= never 2= sometimes 3= always	

E.4	I attend organized training on using hearing protective devices at workplace	1= never 2= sometimes 3= always	
E.5	I wear hearing protective devices when working in noisy environment	1= never 2= sometimes 3= always	
E.6	I inform my supervisor when my earplug/muffs are damaged by any means	1= never 2= sometimes 3= always	
E.7	I keep earplug/muffs at home for safety	1= never 2= sometimes 3= always	
E.8	I keep earplug/muff at special places in my workplace	1= never 2= sometimes 3= always	
E.9	I get information from health and safety committee on noise control	1= never 2= sometimes 3= always	
E.10	I undergo ear screening test annually to discover my hearing status	1= never 2= sometimes 3= always	
E.11	I share my audiometry result with my employer	1= never 2= sometimes 3= always	
E.12	I share my audiometry results with health and safety representative	1= never 2= sometimes 3= always	

ANNEX IIIa: A checklist for walk through survey for iron and steel industries in Dar es salaam, Tanzania

AIM: To describe the workplace environment with respect to noise sources in iron and steel industries in Tanzania

Date of survey..

1. **INDUSTRY IDENTIFICATION**

i. Name of Industry....................................... Owner...

ii. Location..

iii. Address: ....

iv. Nature of work: **..**

v. Year started operation: ....

vi. Number of sections................ With high noise level.................

vii. Total number of employees: .... (M/F) M= ...., F=........

viii. Average production rate/day..

ix. Number of shifts ………. Start at………. end at …….

x. Does the industry have a standard map/floor plan? (Yes/No) ....

xi. If yes in (x) above can the flow plan be availed? (Yes/No

xii. Make a rough sketch if flow plan is not available

xiii. Names and tittles of those participated in walkthrough survey

Name	**Position**	**Task employed to perform**

2. SOURCES OF NOISE

Section	Equipment/machine capable of producing noise	Type of noise produced [impulse/continuous]	Year installed	Noise control measures available to this equipment (engineering control)	No. of workers in section		Shift pattern (if available)	Availability of production line sketch (Yes/No)	Tasks performed at this section
					M	F			
									i. .... ii. .... iii. .... iv. .... v. .... **vi.** ....
									i. .... ii. .... iii. .... iv. .... v. .... vi. ....
									i. .... ii. .... iii. .... iv. .... v. .... vi. ....
									i. .... ii. .... iii. .... iv. .... v. .... vi. ....

3. Hazard identification

Interview five (05) selected workers from each industry who are knowledgeable on working environment

Ask /observe	**Yes**	**No**
<u>(observe)</u> Is a raised voice needed to communicate with someone that is only about one meter away?		
Do workers complain that there is too much noise? (Explain)		
Do workers say that they can’t hear each other or hear instructions or warning signals? (describe which situation/working period)		
Do people working in the area notice a reduction in hearing over the course of the day? (This reduction might not be noticed until after work.)		
Do workers experience any of the following: (a) ringing in the ears (b) the same sound having a different tone in each ear (c) blurred hearing		
<u>(observe)</u> Are personal hearing protectors provided?		
<u>(observe)</u> If yes, are they used?		
<u>(observe)</u> Are signs, indicating that personal hearing protectors should be worn, posted at the entrance or in the work area?		
<u>(Ask)</u> Do employees undergo baseline audiometry? or any planned periodic medical examination?		

4. Training on Hearing Conservation

Determine whether	**Yes**	**No**
i. Is there any Occupational Safety and Health training conducted at workplace (verify documentation)		
ii. If yes. Does it cover hearing conservation?		

iii.	Standards of noise exposure limits are available and documented?		
iv.	Health and safety committees available and functional? (verify documentation)		

- **Additional notes:**

ANNEX IIIb: ITIFAKI (UTARATIBU) YA UCHUNGUZI WA KIWANGO CHA USIKIVU

Namba ya Mshiriki: ………………………… Tarehe ya Uchunguzi: …………………….

A. UTANGULIZI

(rejea form ya mshiriki kutoa idhini ya kushiriki kwenye utafiti)

B. UCHUNGUZI WA AWALI WA MFUMO WA HEWA NA MAAMBUKIZI YA SIKIO

1. Je una dalili zifuatazo?
   a. Kamasi kutoka puani? Ndiyo/Hapana
   b. Kutoka usaha masikioni? Ndiyo/Hapana

C. MAZINGIRA YA KELELE SIKU MOJA KABLA YA UPIMAJI

i. Je ulitoka kazini muda gani jana/ au juzi?

ii. Tarehe ya siku ulipotoka kazini ……………… Muda ………………………

iii. Je ulivaa vizuia kelele masikioni ulipokuwa kazini? Ndiyo/ Hapana

D. UCHUNGUZI WA AWALI WA SIKIO

1. Chunguza uwepo wa nta au uchafu katika njia ya sikio kwa kila sikio.

KUSHOTO ☐ KULIA ☐

2. Chunguza mfereji wa sikio

KUSHOTO ☐ KULIA ☐

3. Chunguza ngoma ya sikio

SIKIO LA KULIA: kawaida/ina jeraha/imetoboka

SIKIO LA KUSHOTO: kawaida/ina jeraha/imetoboka

4. Uchunguzi mwingine wa SIKIO na MAONI kwa ujumla.

E. UCHUNGUZI WA KIWANGO CHA USIKIVU

Melekezo (yametoholewa kutoka mwongozo wa WHO)

Je huwa unasikia vizuri sikio moja zaidi ya jingine? (Kama jibu ni ndiyo, ni SIKIO lipi. Kama jibu ni NDIYO, uliza ni sikio lipi. Endapo jibu ni HAPANA, anza na sikio la KULIA.) Utakuwa ukisikia mlio wa sauti nyembamba, Kwanza, kwenye sikio lako <linalosikia vizuri au sikio la kulia> na kisha sikio lako < jingine au la kushoto>. Mlio wa sauti utakuwa wa kufuatana na punde kutakuwa na ukimya. Pindi utakaposikia mlio wa sauti hiyo < bonyeza kitufe ulichonacho mkononi> ili kuonesha kuwa umesikia. Mlio utapungua kila mara kwa kadri tunavyoendelea. <Kumbuka kubonyeza kitufe ulichonacho mkononi kila mara usikiapo mlio wa sauti>. Mlio wa sauti utabadilika, kwanza mlio utazidi kuwa mwembamba na kisha utaongezeka. Uchunguzi wa sikio lako < jingine au la kulia> hautafanyika hadi uchunguzi wa sikio lako < linalosikia vizuri au la kulia> utakapokuwa umekamilika kwa frequency zote. Endapo utakuwa na uhakika wa kusikia mlio wa sauti, hauhitajiki kusubiri hadi ukimya <bonyeza kitufe ulichonacho mkononi>. Na, hauhitajiki <kubonyeza kifute kwa muda mrefu> pindi usikiapo mlio wa sauti. Unaweza tu < kubonyeza kitufe ulichonacho mkononi na kukiachia> kwa mara moja. Kama huna swali, nakuwekea visikilizia sauti masikioni (headphones) ili tuanze kufanya uchunguzi (JIBU swali lolote litakaloulizwa). Baada ya kumaliza upimaji, subiri niondoe visikilizia sauti (headphones) masikioni.

Namna ya kufanya uchunguzi wa kiwango cha usikivu

- **a.** Mfanye mshiriki awe huru na mazingira ya upimaji
- **b.** Kagua Kifaa (Audiometer) na vifaa vyake kama vipo sawa kwa upimaji.
- **c.** Washa kifaa cha upimaji (Audiometer)
- **d.** Pitia ufanyaji kazi wa kifaa na jiridhishe
- **e.** Hakikisha Frequency zinazotumika katika vipimo ni sahihi yaani; - 1000, 2000, 3000, 4000, 6000, 8000 Hz kisha 500 Hz, 250 Hz na malizia na 1000 Hz.
- **f.** Weka visikilizia sauti (headphones) masikioni mwa mpimwaji na umpatie kitufe cha kubonyeza mwitikio.
- **g.** Chunguza tena kama kila kisikilizia sauti vimevishwa kwenye sikio stahiki.
- **h.** Bonyeza sauti ya kusikilizia ili kutoa mfano wa mlio sahihi.

i. Kubaliana na mpimwaji juu ya utaratibu wa kupima

j. Anza kufanya upimaji.

MAJIBU:

F. HATUA ZA KUFANYA

Ahsante kwa Ushirikiano

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Variability and Determinants of Occupational Noise Exposure Among Iron and Steel Factory Workers in Tanzania

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Abstract

Background: Machines, processes, and tasks in the iron and steel factories may produce noise levels that are harmful to hearing if not properly controlled. Studies documenting noise exposure levels and related determinants in sub-Saharan Africa, including Tanzania are lacking. The aim of this study was to document noise exposure and to identify determinants of noise exposure with a view to establishing an effective hearing conservation programme.
Methods: A walk-through survey was conducted to describe the working environment in terms of noise sources in four metal factories (A–D) in Tanzania. Noise measurements were conducted by both personal, full-shift noise measurements (8 h) using dosimeters and area measurements (10-s measurements) using a sound level meter. A total of 163 participants had repeated personal noise measurements (Factory A: 46 participants, B: 43, C: 34, and D: 40). Workers were randomly selected and categorized into 13 exposure groups according to their job. Linear mixed effects models were used to identify significant determinants of noise exposure in the furnace section and the rolling mill section.
Results: The average personal noise exposure in the four factories was 92.0 dB(A) (range of job group means; 85.4–96.2 dB(A)) (n = 326). Personal exposure was significantly higher in the rolling mill section (93.0 dB(A)) than in the furnace section (89.6 dB(A)). Among the job groups, the cutters located in the rolling mill section had the highest noise exposure (96.2 dB(A)). In the furnace section, furnace installation (below the ground floor), manual handling of raw materials/billets/crowbars, and billet weighing/transfer were significant determinants explaining 40% of the total variance in personal noise exposure. In the rolling mill section, the size of the cutting machine, steel billet weight

and feeding re-heating furnace explained 46% of the total variance in personal noise exposure. The mean noise level of the area measurements was 90.5 dB(A) (n = 376).

Conclusion: Workers in the four iron and steel factories in Tanzania were exposed to average noise of 92.0 dB(A), without using hearing protection, implying a high risk of developing hearing loss. Task and factory level determinants were identified in the furnace and the rolling mill sections of the plant, which can inform noise control in factories with similar characteristics.

Keywords: iron and steel factories; noise exposure; occupational; Tanzania

Introduction

Occupational noise exposure and related hearing impairment is a public health problem in sub-Saharan Africa that has been neglected. This region is estimated to have an increasing occurrence of occupational-related noise-induced hearing loss due to rapid ongoing industrialization (Concha-Barrientos *et al.*, 2004; Nelson *et al.*, 2005). Research has shown that iron and steel factories in industrialized countries are among the workplaces with high noise levels (Lie *et al.*, 2016), but only a few studies have been conducted in developing countries on noise exposure in these same industries (Kamal *et al.*, 1989; Pandya and Dharmadhikari, 2002; Ologe *et al.*, 2006; Singh *et al.*, 2013; Noweir *et al.*, 2014). To our knowledge, no such studies have been undertaken in sub-Saharan Africa.

Steel products in Africa are important for economic development as it is essential for infrastructure development. In 2013, it was estimated that 52% of the total worldwide steel production was used in construction work such as bridges, rails, towers, machinery, and buildings. Of this, 58% was used in developing countries including Africa, where steel use has escalated from 31.9 metric tonnes to 39 metric tonnes from 2009 to 2016 (World Steel Association, 2016).

In recent years, Tanzania has enjoyed economic growth complemented with investments in industry. The current government policy is shifting towards inclusive and sustainable industrialization (translated as '*Tanzania ya viwanda*'), which entails more focus on industrial investments in Tanzania. This is likely to become the trend in other sub-Saharan African countries. The number of steel manufacturing factories is expected to increase in Tanzania and in other developing countries to meet rising demand. However, the working condition in Tanzanian industry has received little attention, and appropriate noise control interventions in the iron and steel factories are lacking. This implies that employees run the risk of exposure to noise at work. Documenting occupational noise exposure and the tasks that give rise to the noise in iron and steel factories is necessary to enable policy and decision makers to implement measures to prevent hearing loss among workers (International Labour Organization, 2005; Morata and Meinke, 2016) as well as other adverse effects due to noise exposure among employees (Girard *et al.*, 2009). Therefore, the purpose of this study was to document occupational noise exposure levels and to identify potential determinants of noise exposure in iron and steel factories. Assessment and description of the noise sources is a prerequisite for formulation and implementation of effective noise control programmes (Pandya and Dharmadhikari, 2002).

Materials and Methods

Study setting

This exposure study was conducted among workers in the production line in four iron and steel factories located in different industrial areas in Dar es salaam, Tanzania. The study started in June 2016 and ended in June 2017.

The steel manufacturing process

The manufacturing process in the four steel factories is divided into two separate sections—the furnace section, where metal scraps are processed into steel billets, and the rolling mill section, where steel bars are manufactured.

The raw materials commonly used are domestically available metal scraps and imported billet sheets. In the furnace section, metal scraps are melted in the induction furnace to form molten steel with floating furnace slag which is removed by raking. The molten steel is then poured into a ladle and then into smaller ladles/crucibles which are carried manually to the prepared molds of varied sizes to form steel billets. The billets are cooled and later weighed before rolling mill processing. Noise is emitted by the machines and manual handling of metal scraps, steel billets, and feeding metal scraps into the furnace oven. Other sources of noise include the weighing process and the moving and dropping of billets onto the weighing scale.

The rolling mill process involve heating steel billets to a temperature of about 960°C in a gas furnace, after which the billets are transferred as red-hot bars to a roughing machine, where they are shaped and lengthened. Electric motor-operated conveyor rails transport the hot steel billets between the machines. The red-hot bars are fed (manually in factories A, B, and D or automatically in factory C) into six serially arranged rolling mill machines where steel bars are manufactured as required. Steel bars are then moved into a cooling bed and cut into standard lengths (normally 6 m). All these processes involve noise emission from the operating machines, movement of materials and the operating tasks. The products are bend-tested to ensure conformity with required standards. The final products are bundled and stored for transport.

Iron and steel factories involved in the study

A list of 22 registered iron and steel factories in the Eastern Tanzania Zone was obtained from the Occupational Safety and Health Authority (OSHA). The factories were scrutinized individually to ensure that they were operational and accessible, had complete steel production processes, a known factory address and at least 50 permanent employees. Twelve factories qualified. Of these, five factories were randomly selected. Initial contact was made between December 2015 and January 2016. One factory changed production just prior to project start-up and was therefore excluded from the study. We were left with a sample comprising four factories.

We held meetings with the factory administration to present the purpose of the study and seek permission to conduct the project. All four factories agreed to participate and a contact personnel in the factory helped the research team to plan the noise measurements. The participating factories had 588 factory workers (excluding casual labourers) in the production line, and half of these worked the day shift. In all factories, rotation of workers in their job groups between day and night shifts were done after every 2 weeks. Only the day shift was used for noise measurements. Similar tasks were conducted during night shift; hence, workers might have been potentially exposed to similar noise level. However, we did not cover the details for the night shift because we did not visit factories during night. Workers in the maintenance section were excluded because their tasks involved sprinkling water into the rolling mill machines, and this was deemed potentially harmful to the noise dosimeters. However, these workers spent most of their working hours in the rolling mill section and hence they were likely to be exposed to noise levels similarly to rolling mill job groups.

Walk-through survey

Prior to taking noise measurements, the research team accompanied by a factory management representative conducted a walk-through survey in each factory. We collected information about when the factory started steel production, types of equipment and machines producing noise, any changes of equipment and machines, annual production capacity, a list of names and number of workers, available job groups/titles, shifts and safety, and health policy. Moreover, we observed the availability and use of hearing protective devices. This information was used to describe the workplace environment in relation to noise levels and to identify potential noise exposure determinants.

Personal noise measurements

Study participants

The two main factory sections—the furnace and the rolling mill—were manned by 13 job groups. Workers in the same job group were assumed to constitute similar exposure groups because they were doing similar tasks in the same type of work area (Mulhausen and Damiano, 2006). Consequently, the workers were categorized into a total of 13 exposure groups according to their job. These exposure groups/job groups were melters, moulders, billet shifters, workers at billet weighing, and workers at continuous casting machines (CCM) in the furnace section; and tongsmen, pushers, firemen, cutters, workers at the cooling bed, workers at roughing, rolling mill automated machine operators, and shearers in the rolling mill section. For exposure studies, Rappaport and Kupper suggested 10–20 measurements in each exposure group, i.e. repeated measurements of 5–10 workers (Rappaport *et al*., 1993; Rappaport and Kupper, 2008). Thus, we aimed at randomly selecting 5–10 workers from each job group in each factory. However, not all job groups were available in each factory, and when they were available, the number of workers per job group varied from 2 to 35. All workers were selected if the job group comprised five or fewer workers.

The number of production line workers participating in the personal noise exposure measurements totalled 163:46 from factory A, 43 from factory B, 34 from factory C, and 40 from factory D. As one repeated measurement was performed for all, a total of 326 noise exposure measurements were conducted. The measurements in the furnace section were performed from 0700 to 1600 and in the rolling mills from 0700 to 1700.

Instrumentation

Full-shift personal noise measurements were conducted according to ISO standard 9612:2009 (International

Standard Organization, 2009) using personal noise dosimeters (Brüel and Kjær type 4448). The dosimeters had a measurement range from 50 to 140 dB [A – weighted noise level ($L_{p,\mathrm{A}}$)], and a 3-dB exchange rate was used. The dosimeters logged noise data each minute during the measurement period. The instruments were calibrated before and after the sampling period, and no shifts in baseline were detected. The dosimeters were attached to workers' shoulder approximately 10–15 cm from the ear. Workers were instructed to handle the dosimeters carefully while working, not to touch or shout into the microphone and to report any mishap with the instrument during the measurement period. Two members of the research team circulated two to five times during the sampling period, checking if dosimeters worked properly. During resting periods, the workers were instructed not to tamper with the devices. The researchers recorded tasks performed by each worker on a sampling sheet including information on noise sources. The workers confirmed this information during lunch and at the end of the sampling period. The values recorded from the dosimeters were the start- and end-time of the sampling period, the A-weighted equivalent noise level for the duration of the measurement ($L_{p,\mathrm{A,eq}T}$) and the C-weighted peak noise level ($L_{p,\mathrm{Cpeak}}$). The data were normalized to daily noise exposure levels ($L_{\mathrm{EX,8h}}$) by noise exposure groups (job groups), using the following equation:

$$L_{\mathrm{EX,8h}} = \mathrm{L}_{p,\mathrm{A,eq}Te} + 10\log^{(Te/T0)} \tag{1}$$

where $L_{p,\mathrm{A,eq}Te}$ is the A-weighted equivalent continuous sound pressure level from dosimeter, Te is the measurement period, and $T0$ is the reference duration, equal to 8 h.

Area noise measurement

Area measurements were performed using a portable, hand-held sound level meter (Brüel and Kjær type 2250). A total of 376 measurements were conducted, i.e. 130 measurements in factory A, 108 in B, 60 in C, and 78 in factory D. The instrument was calibrated before and after each measurement day. The measurements were taken under apparently stable working conditions with the assumption that the measured result would be representative of the prevailing working situation. The area measurement points were at an approximate distance of 2 m from one another, and covered the whole working section allocated for the respective job groups. In physical hazardous areas, in which workers' sideways movements were limited, such as for tongsmen, only points at each working position in a straight line backwards (approximately 2 m) were measured. Thus, the total number of measurements were influenced by the size of the working area designated for each job group, i.e. the larger the working area, the higher number of measurements. The number of area measurements for the different working areas ranged between 5 (for shearers) and 83 (for moulders). Measurements were conducted in a single day in each factory, and once for each measurement point. For uniformity of analysis of data from various job groups, each measurement was taken for 10 s and A-weighted equivalent noise levels ($L_{p,\mathrm{A,eq10s}}$) were recorded. For averaging the results in each work area, a quantity was calculated using the equation (1):

$$p^2 / p_0^{\,2} = 10^{(Lp,\mathrm{A,eq10s}/10)} \tag{2}$$

where p is the sound pressure level corresponding to $L_{p,\mathrm{A,eq10s}}$ and p_0 is a reference value set at 20 μPa. By using formula (2), a mean sound pressure level was calculated as:

$$\mathrm{mean}L_{p,\mathrm{A,eq10s}} = 10 * \log(\mathrm{mean}\left(p / p_0\right)^2) \tag{3}$$

The A weighted noise levels ($L_{p,\mathrm{A}}$) were reported in decibel (dB(A)).

Occupational exposure limit (OEL) for noise

In Tanzania, the OEL for occupational noise exposure is 85 dB(A) as an 8-h time-weighted average and is used by OSHA Tanzania for compliance. This level is equal to the Recommended Exposure Limit for noise from The National Institute for Occupational Safety and Health (NIOSH), United States (NIOSH, 1998). A peak noise level of 135 dB(C) was used as the lower action value that is also used in the European Union (EU) and the UK for the peak sound pressure (European Parliament and Council, 2003; Health and Safety Executive, 2005).

Statistical analysis

Data from data collection tools were consolidated into Microsoft Excel 2016. IBM SPSS version 24 for Windows was used in statistical analysis. Descriptive statistics (mean, standard deviation, and percentage of measurements with levels above OEL) were computed for $L_{p,\mathrm{A}}$ for both area and personal measurements. The number of personal measurements with $L_{p,\mathrm{Cpeak}}$ exceeding 135dB(C) were identified. The difference between area and personal noise exposure was analysed using linear mixed effects model to account for repeated measurements within job groups and factories. Noise levels from all personal and area measurements were the dependent variable, sample type (personal measurement versus area measurement) was entered as fixed effect while factory and job group were entered as random factors in the mixed effects model.

A one-way analysis of variance (ANOVA) was conducted to explore the difference in mean noise exposure (dB(A)) between job groups. Additionally, ANOVA using the Games–Howell test was conducted to explore the difference in the noise exposure between the four factories; A, B, C, and D.

Potential, dichotomous noise determinants were grouped into two groups. The first group comprised factory-related determinants, i.e. size of the cutting machines (large/small); presence of roughing machine (yes/no); separated shearing machines (yes/no); steel billet weight (20-30kgs/100-120kgs); furnace installation (above ground floor/below ground floor); production capacity (5400–15,400/80,000 tonnes per year), and rolling mill plant operation technology (traditional, manual/modern, automated). The second group comprised task-related determinants, i.e. manual handing of raw materials/billets/crowbars (yes/no); feeding the furnace oven (yes/no); pouring molten steel into molds (yes/no); billet weighing/transfer (yes/no); feeding re-heating furnace (yes/no); feeding roughing machine (yes/no); work at rolling machines (yes/no); and steel bar cooling/cutting (yes/no). The job groups assigned to manual handling of raw materials/billets/crowbars were melters, billet shifters, pushers, tongsmen, and workers at roughing. In preliminary analyses for exposure modelling, independent sample *t*-test was used to analyse differences in noise exposure within each of these determinants.

Linear mixed effects models were used to identify significant explanatory variables/determinants for noise exposure in the furnace and in the rolling mill sections, respectively. Personal noise exposure ($L_{EX,8h}$) was entered as a dependent variable. Worker identification and factory were entered as random effects. Significant determinants ($P < 0.05$) from the initial *t*-test analysis (rolling mill plant technology, production capacity, furnace installation, steel billet weight, separated shearing machine, size of the cutting machine, manual handing of raw materials/ billets/crowbars, pouring molten steel into molds, billet weighing/transfer, and feeding re-heating furnace) were entered as fixed effects in two steps starting with process-related and then task-related determinants. Intercorrelation between determinants was tested with Spearman correlation test. When two or more determinants correlated, the determinant that contributed to the highest percentage of explained variability in noise level was chosen. Determinants were retained in the models when significant ($P < 0.\ 05$).

Ethical consideration

Clearance was issued by The Regional Committee for Medical and Health Research Ethics (REK- VEST) in Norway and the Muhimbili University of Health and Allied Sciences (MUHAS) Ethics Committee. Permission to conduct the study was also sought and acquired from the respective iron and steel factories. Each participating worker gave written, informed consent. No information about individual participants was at any point made available to the employers.

Results

The walk-through survey

The four iron and steel factories had generally similar semi-open building structures comprised inverted v-shaped continuous roofing supported by metal beams or blocks from the ground allowing for installation of machines, equipment and for ventilation. The building had no sound absorbents. In the rolling mill sections, one side of solid walls were constructed by cement-blocks and had air vents in it approximately 1.5 m above the foundation. Mobile cranes were installed in between the roofing structure and the supporting metal beams.

Table 1 shows similarities and differences in major characteristics among the four factories. The induction furnaces of the factories were raised to approximately 3.5 m above the ground surfaces except for factory D, where the furnace was below the ground surface. In factory B, the furnace and rolling mill sections were in separate plots, and steel billets were transported to the rolling mill section by vehicles. Factory A, B, and D had manually operated rolling mill machines with minor differences. Factory C had an automated rolling machine. In addition, factory C had a CCM for making billets from molten steel (equivalent to moulding section in the other factories). Furthermore, the annual production capacity, the steel billet weight and size of the cutting machine all varied between the factories. The workers were not observed wearing hearing protective devices. The various machines, as well as colliding metals during different tasks, produced both continuous and intermittent noise (Table 2).

Noise exposure levels

Personal noise exposure

The average personal noise exposure ($L_{EX,8h}$) was 92.0 dB (A) (n = 326) (Table 3). The mean measurement time was 7.3 (SD = 0.9) hours. About 90% of all measurements were above the OEL of 85 dB(A). There was a significant difference in average noise exposure among the four factories ($P < 0.01$). Factory B had the

Table 1. Characteristics of the four (A, B, C, and D) iron and steel factories in Tanzania.

Characteristic	Description	Factories			
		A	B	C	D
Year established		1997	1995	2004	2005
Production line workers		142	179	120	147
Major machine changes	Induction Furnace	3–5 tonnes in 2014	3–5 tonnes	3–5 tonnes in 2006	3 tons installed in 2014
	Rolling mills	Motor running the flywheel in 2015		Automated system plant installed	
Production capacity (tons/year)		12,000–15,400	6000–10,000	80,000	5400–7200
Size of the furnace section		65 m length × 29 m wide	65 m length × 32 m wide	130 m length × 60 m wide and housed both furnace, continuous casting machines and rolling mill section	50 m length × 35 m wide
Size of the rolling mill section		98 m length × 30 m wide	98 m length × 30 m wide		97 m length × 30 m wide
Rolling mill operation system	Automated with CCM	-	-	Present	-
Roughing machine	Free-standing unit	-	Present	-	Present
Furnace installation	3.5 m above the floor	Present	Present	Present	-
	Below the floor surface	-	-	-	Present
Shearing machine	Free-standing and separate	Present	-	-	-
	Connected with cutting unit	-	Present	Present	Present
Cutting machine	Large	-	Present	-	-
	Small	Present	-	Present	Present
Steel billet weight used in steel production	20–30 kg	Present	-	-	Present
	100–120 kg	-	Present	Present	-
Warning signs for noise hazard		-	Present	Present	-

Table 2. Description of job groups, main tasks, and sources of noise in the furnace and rolling mill sections of the four (A, B, C, and D) iron and steel factories in Tanzania.

Section	Job group	Main task	Sources of noise
Furnace Section	Melters	Offloading metal scraps using cranes; final sorting of metal scraps to remove explosives, feeding the induction furnace oven with raw materials using hands, handcarts, and crowbars.	Droning noise from operating induction furnace plant. Noise from collision of metals scraps during offloading by overhead crane, loading and offloading into handcarts; loading of metal scraps into furnace; siren. Noise from explosive materials accidentally fed into furnace
	Moulders	Pouring molten steel from ladle to turndish and then transfer by crucibles to moulds where it cools to form steel billets.	Noise from siren and noise generated from induction furnace section as these two are under same roof except for factory B.
	Billet shifters	Transfer of steel billet from the furnace section to the pusher.	Noise from siren, weighing billets, and loading billets into handcarts transported to pusher section. Noise generated from induction furnace
	Workers at billet weighing	Weighing and recording steel billets for the steel production process.	Noise generated by putting billets on the weigh scale, and loading billets into handcarts transported to pusher section.
	Workers at CCM (available only in factory C)	Operate an automatic machine that receives molten steel to form steel billets.	Droning noise from CCM machinery. Noise from adjacent induction furnace, siren, pusher, and rolling mill sections (as they are all under same roof). Reflective sounds
Rolling Mill Section	Pusher	Feeds re-heating gas furnace with billets at charging side.	Droning noise from operating gas furnace, offloading billets from handcarts, loading of billets into the pusher machine. Noise from adjacent operating rolling machines, electric fans, siren and motors. Reflective sounds
	Firemen	Controlling re-heating billets into red-hot process. Removing red-hot billets from gas furnace using crow bars and direct them into an electric operated metal conveyor.	Same as pusher. Noise from collision of red-hot billets, conveyor rails and sides.
	Workers at roughing	Flatten red-hot billets (back and forth) into thinner and more elongated shape than the original steel billet.	Same as in Firemen. Noise from pressurizing/flattening process
	Tongsmen Machine operators (in factory C)	Steel bar rolling mills.	As in roughing section. Noise generated from frequent metal impact from moving metal rods into rolling mills and the conveyor system and from the hammering of metal rods stuck in the machines.
	Workers at cooling bed	Moving hot steel bars from rolling machines into a cooling platform.	Droning noise from rolling mill and cutting machines, siren, reflective sound, moving hot steel bars through metal conveyor beams and rails

Table 2. *Continued*

Section	Job group	Main task	Sources of noise
	Cutters/bundlers	Cutting steel bars into required length (normally 6 m) and bundling steel bars for storage/transport.	Noise from cutting machine, moving steel bars into conveyors. Noise from rolling mills machines. Loading of finished products immediately after cutting sometimes produced noise.
	Shearers	Cutting rejected steel bars into chunks for recycling.	Droning noise from the operating machines, siren. Noise from pieces of steel dropped into carrying buckets.

Table 3. Noise levels (personal and area) in four iron and steel factories in Tanzania: comparison between factories and job groups.

	Job group	Personal noise exposure					Area noise level		
		$L_{EX,8h}$ in dB(A)[a]					$L_{p,A,eq10s}$ in dB(A)[d]		
		N	Mean	SD	%> 85 dB(A)[b]	NP (%)[c]	*N*	Mean	SD
All factories	**All measurements**	326	92.0	3.4	90	107 (33)	376	90.5	6.0
Furnace section	Moulders	34	88.3	3.2	50	9 (26)	83	81.6	2.9
	Melters	54	89.5	2.6	94	25 (46)	64	88.1	2.9
	Billet shifters	12	87.9	1.7	100	8 (67)	10	91.0	2.4
	Workers at billet weighing	6	92.5	1.3	100	1 (17)	10	94.2	3.7
	Workers at CCM	12	87.4	0.5	83	1 (1)	9	94.1	1.4
	Furnace section	118	89.6	3.0		44 (37)	176	91.6	3.6
Rolling mill section	Pushers	38	91.4	2.8	92	16 (42)	35	89.4	5.0
	Firemen	26	93.1	2.1	100	9 (35)	26	91.4	2.3
	Tongsmen	36	93.4	3.1	100	15 (42)	37	92.7	2.7
	Workers at cooling bed	28	92.2	2.6	100	5 (21)	28	91.3	5.3
	Workers at roughing	24	93.6	2.6	100	12 (50)	24	94.8	3.8
	Cutters/bundlers	46	96.2	5.1	93	5 (11)	39	93.3	6.4
	Machine operators-automated system	4	92.7	0.2	100	-	6	83.1	3.1
	Shearers	6	85.4	1.3	50	1 (17)	5	93.3	2.7
	Rolling mill section	208	93.0	3.7		63 (30)	200	92.1	2.9

[a]$L_{EX,8h}$ The A-weighted personal noise exposure calculated using equation no. (1) above; [b]%>85OEL (occupational exposure limit) = [number of measurements >85 (dB(A)/total number of measurements (dB(A)]×100; [c]NP, number of measurements with $L_{p,Cpeak}$ > 135 dB(C); [d]$L_{p,A,eq10s}$ the A-weighted equivalent area noise levels measured in 10 s.

highest equivalent noise exposure followed by factory C, while factory D had the lowest noise exposure [see Supplementary Table S1 in the Supplementary Material (available at *Annals of Work Exposures and Health* online)]. Personal exposure was significantly higher in the rolling mill section (93.0 dB(A)) than in the furnace section (89.7 dB(A)). The exposure was significantly higher in the rolling mill section than in the furnace for factories B, C, and D, but not in factory A (Fig. 1). There was a significant difference at the $P < 0.05$ level in noise exposure among the 13 job groups ($P < 0.001$). The shearers had the lowest and the cutters/bundlers had the highest equivalent noise exposure (Table 3).

Thirty-three percent ($n = 108$) of the personal measurements had $L_{p,Cpeak}$ exceeding 135 dB(C) of which factory A had the highest fraction (41%) while factory C had the lowest fraction (28%). Among the job groups, the billet shifters had the highest percent of measurements with such peak levels (67%) (Table 3).

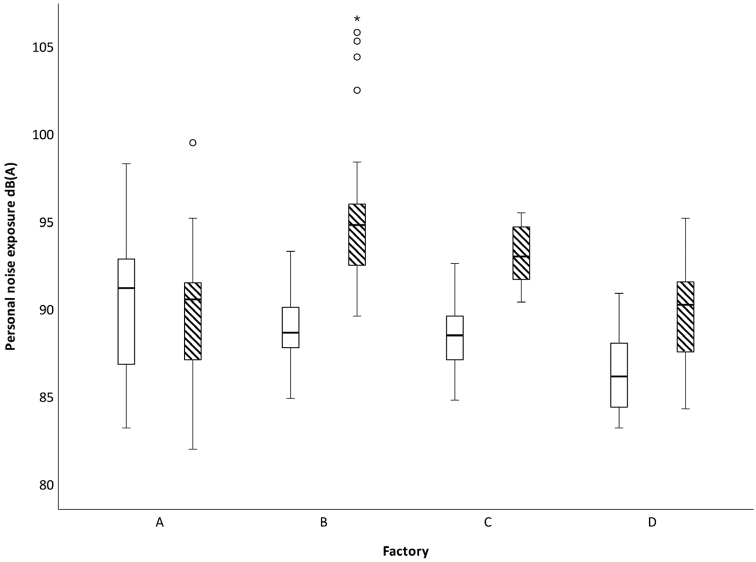

Figure 1. Personal noise exposure ($n = 326$) in the furnace (open boxes) and rolling mill (hatched boxes) sections for the four iron and steel factories (A, B, C, and D) in Tanzania. The boxes contain fifty percent of the noise measurements, the solid line within the boxes represents the median value and the whiskers indicate 5th and 95th percentiles, respectively.

Area noise exposure

The average area noise level was 90.5 dB(A) (Table 3). Factory B had the highest average noise level while factory D had the lowest level [see Supplementary Table S1 in the Supplementary Material (available at *Annals of Work Exposures and Health* online)].

The personal noise exposure was significantly higher [2.6 dB (A); 95 confidence interval (CI) = 2.1–3.1] compared to the corresponding area measurements (Linear mixed effects model, $P < 0.001$).

Noise exposure models

In preliminary analysis for exposure modelling in the furnace section, there were significant differences in personal noise exposure within the four dichotomous variables: furnace installation, manual handing of raw materials/billets/crowbars, pouring molten steel into molds, and billet weighing/transfer. In the rolling mill section, the difference in noise exposure was significant within the six variables: rolling mill technology, steel billet weight, production capacity, separated shearing machine, size of the cutting machine, and feeding re-heating furnace (independent sample *t*-test) (Table 4). However, in the furnace section, one determinant, i.e. pouring molten steel into molds significantly correlated with manual handing of raw materials/billets/crowbars (Spearman correlation, $r = -0.7$, $P = 0.01$). In the rolling mill section, steel billet weight significantly correlated with the rolling mill technology (Spearman correlation, $r = -0.5$, $P = 0.01$), the production capacity (Spearman correlation, $r = -0.5$, $P = 0.01$), and the separated shearing machine (Spearman correlation, $r = -0.4$, $P = 0.01$) determinants. Similarly, the size of cutting machine correlated significantly with the rolling mill technology and the production capacity determinants (Spearman correlation, $r_1 = 0.3$, $P_1 = 0.01$; $r_2 = 0.3$, $P_2 = 0.01$).

In the linear mixed effects models for noise exposure in the furnace, the three variables: furnace installation, billet weighing/transfer, and manual handing or raw materials/billets/crowbars were significant determinants, and explained 40% of the total variance in noise exposure. All of the between-factory variance was explained with 45% of the between-worker variance. However, the within-worker variance was not explained. Furnace installation below the ground floor was associated with a 2.3 dB(A) reduction in noise exposure whereas manual handling and billet weighing/transfer increased noise exposure by 2.2 dB(A) and 2.1dB(A), respectively (Table 5).

In the rolling mill section, size of cutting machine, the steel billet weight, and feeding re-heating furnace were significant determinants, and explained 46% of the total variance in noise exposure (Table 5). All of

Table 4. Potential determinants for personal noise exposure ($L_{EX,8h}$) in decibel (dB(A)) in the four (A, B, C, and D) iron and steel factories in Tanzania.

Determinant	Attributes	Furnace section			Rolling mill section		
		N	Mean (SD)	[a]*P* value	*N*	Mean (SD)	[a]*P* value
Factory-related determinants							
Rolling mill technology	0 = Traditional, manual				164	91.6 (4.1)	<0.001
	1 = Modern, automated with CCM				44	93.2 (1.6)	
Presence of the roughing machine	0 = No				86	91.6 (3.0)	0.2
	1 = Yes				122	92.2 (4.2)	
Steel billet weight (kg)	0 = light (20–30)	60	89.1 (3.7)	0.4	106	89.7 (2.8)	<0.001
	1 = Heavy (100–120)	58	88.7 (2.0)		102	94.2 (3.2)	
Production capacity(tonnes/year)	0 = Low (6000–15,400)	94	89.0 (3.2)	0.3	164	91.6 (4.1)	<0.001
	1 = High (80,000)	24	88.4 (1.9)		44	93.2 (1.6)	
Separated shearing machine	0 = No				166	92.5 (3.5)	<0.001
	1 = Yes				42	89.8 (3.3)	
Furnace installation	0 = 3.5 m above the ground floor	102	89.3 (2.9)	<0.001			
	1 = Below the ground floor	16	86.4 (2.3)				
Size of the cutting machine	0 = Small, well lubricated				150	90.8 (3.0)	<0.001
	1 = Large, not well lubricated				58	95.0 (3.8)	
Task-related determinants							
Manual handing of raw materials/billets/crowbars	0 = no	46	87.1 (2.9)	<0.001	146	92.0 (4.1)	0.5
	1 = Yes, most of time	72	90.0 (2.4)		62	91.7 (2.9)	
Feeding furnace oven	0 = no	64	88.5 (3.4)	0.1			
	1 = Yes	54	89.4 (2.3)				
Pouring molten steel into moulds	0 = no	84	89.7 (2.5)	<0.001			
	1 = Yes	34	87.0 (3.2)				
Billet weighing/transfer	0 = no	100	88.3 (2.8)	<0.001			
	1 = Yes	18	92.0 (1.4)				
Feeding re-heating furnace	0 = no				170	92.2 (3.9)	
	1 = Yes				38	90.7 (2.7)	0.008
Feeding roughing machine	0 = no				184	91.8 (3.9)	
	1 = Yes				24	93.1 (2.6)	0.09
Work at rolling machines	0 = no				172	91.8 (3.8)	
	1 = Yes				36	92.6 (3.0)	0.2
Steel cooling/cutting	0 = no				134	91.9 (3.2)	
	1 = Yes				74	92.0 (4.6)	0.9

[a]Independent sample *t*-test, significant at $P < 0.05$. *N* = number of personal noise measurements.

the between-factory variance was explained with 9% of between-workers variance. Large cutting machine was associated with an increase of 1.8 dB(A) in noise exposure. Additionally, the large steel billet weight (100–120 kg) was associated with 3.6 dB(A) increase and feeding re-heating furnace with 1.9 dB(A) decrease in noise exposure (Table 5).

Discussion

The workers in the four iron and steel factories were exposed to an average noise of 92 dB(A), with 90% of the personal measurements exceeding the OEL of 85 dB (A). Workers did not use personal hearing protective devices. The noise exposure in the rolling mill section

Table 5. Linear mixed effects model for determinants of A-weighted noise exposure ($L_{EX,8h}$) in decibel (dB(A)) in the furnace and rolling mill sections for the four iron and steel factories in Tanzania.

Determinants	Description	Personal noise exposure (dB(A))			
		Furnace section (N = 118)		Rolling mill section (N = 208)	
		Random effects model β (SE)	Mixed-effects model β (SE)	Random effects model β (SE)	Mixed-effects model β (SE)
	Intercept	88.5 (0.75)***	87.5 (0.44)***	91.9 (2.29)***	90.0 (0.38)***
Factory-related determinants					
Size of the cutting machine	0 = Small				1.8 (0.75)*
	1 = Large				
Furnace installation	0 = 3.5 m above the ground floor				
	1 = Below the ground floor		−2.3 (0.78)**		
Steel billet weight	0 = Light (20–30 kg)				
	1 = Heavy (100–120 kg)		-		3.6 (0.84)***
Task-related determinants					
Manual handing of raw materials, billets and crowbars	0 = no				
	1 = Yes, most of the time		2.2 (0.57)***		
Billet weighing/transfer	0 = no				
	1 = Yes		2.1 (0.93)**		
Feeding re-heating furnace	0 =no				
	1 = yes				−1.9 (0.68)*
Within-worker variance ($ww\delta^2$)		3.30 (0.61)	3.30 (0.61)	2.49 (0.35)	2.49 (0.35)
Between-worker variance ($bw\delta^2$)		4.42 (1.20)	2.43 (0.87)	6.44 (1.10)	5.87 (1.0)
Between-factory variance ($bf\delta^2$)		1.81 (1.92)	-	6.56 (5.59)	-
% of total variance explained by the fixed effects			40		46

***$P < 0.001$, **$P < 0.01$, *$P < 0.05$

was significantly higher than in the furnace section. The workers were found to be exposed to high peak levels, of which 33% of the personal measurements exceeded 135 dB(C). In the noise exposure models for the furnace section, the furnace installation, billet weight, and manual handling of raw materials/billets/crowbars explained 40% of total variance. In the rolling mill section, 46% of the total variance was explained by steel billet weight, the size of the cutting machine and feeding re-heating furnace. The personal noise exposure correlated with the area noise level. To our knowledge, this is the first study from sub-Saharan Africa documenting noise exposure and identifying the determinants for noise exposure in iron and steel factories.

A study conducted among Indian steel industrial workers showed high mean noise levels for both personal (83–130 dB(A)) and area (89–105 dB(A)) measurements (Singh *et al*., 2013). These ranges indicate that groups of workers in the Indian study had even higher noise exposure than reported in our study. For instance, the moulders in the Indian study had a personal noise exposure of 99 dB(A) while we found 88 dB(A) for this job group. The difference in results may be partly explained by differences in tasks, processes, machines, and tools. However, the Indian study did not describe the tasks undertaken by each job group, and this makes it difficult to compare the studies. Our study differs from the Indian study also in methodological aspects, that is, the Indian study did only one personal full-shift measurement per job group while we conducted several measurements per job group.

The linear mixed effects model for the furnace section showed that the task-related determinants, i.e. manual handing of raw materials/billets/crowbars and billet weighing/transfer increased noise exposure by about 2 dB(A)'s each. This was presumably caused by colliding objects in motion, tools and metals when offloading raw materials from vehicles, sorting raw materials/metal scraps, transfer and feeding into the furnace oven, as well as collisions during manual weighing of steel billets. On the other hand, furnace installation below the ground floor reduced the noise exposure by 2 dB(A) probably by reducing the direct sound transmission form the furnace to the workers, suggesting the importance of encompassing noise control considerations in engineering design. The three identified determinants in the furnace explained the between-factory variance and partly the between-workers variance, but not the within-worker variance of noise exposure. This seems logical since furnace installation was a factory-related determinant while manual handling and billet weighing/transfer were linked to job groups' tasks in which there were no changes in the recorded tasks performed from day to day for individual workers and none of the workers changed factory or between the two sections. Additional factors such as changes in production-related activities from day to day for example, volume of work, breakdowns, changes in product specifications, were not recorded and might have caused the unexplained within worker variance.

In the rolling mill section, a 3 dB(A) and almost 2 dB(A) increase in noise were attributed to the use of large billet weight (100–120 kg) and a large cutting machine respectively. The factory that had both two determinants (factory B) recorded the highest mean noise exposure and this was reflected in the particularly high noise level in the working area for the cutters in this factory. Factory C which used large steel billet in steel bar production also recorded high noise compared to other factories that used light billet weight. This may be due to the heavy weight of the steel billet that might result into high impacts with various machines while in motion during steel bar production process. On the other hand, feeding re-heating furnace was the only task-related determinant in this section that was observed to reduce noise by 2 dB(A) presumably since this working area is located at the far end of the rolling mill section and is thus less impacted by high noise level from the rest of working areas where noise is emitted by machines and operations. As for the furnace model, these factory and task-related determinants exclusively explained the between-factory and between-workers variances. Descriptions of roles for these determinants and their contributions to the recorded noise level in this section provide a room for proper noise control.

Our results indicate that design of the factory buildings, location, and type of production machinery and job tasks associated with colliding metal parts contributed to recorded noise exposure. This is closely related to the Indian study that found that manual handling of steel products was an important noise source (Pandya and Dharmadhikari, 2002). The impact of manual handling of metal parts on noise exposure in the present study suggests that training workers to handle metal objects and tools more gently may reduce the noise levels associated with tasks such as weighing of billets and loading the pusher machines. Reducing dropping height and/or installation of vibration-absorbent material on surfaces are recognized measures to reduce noise emission from colliding materials. To our knowledge, documentation of any noise reducing effects related to such factors in steel production facilities are scarce, and none has been conducted in sub-Saharan Africa.

In the present study, we included area measurements to investigate the compliance between these measurements and corresponding personal measurements. Area measurements using sound level meter have been widely used to indicate workers' noise exposure in regions of limited economic resources including African and Asian countries (Pandya and Dharmadhikari, 2002; Warrington and McLoughin, 2005; Ologe *et al.*, 2006; Singh *et al.*, 2013; Noweir *et al.*, 2014). Some reasons to this could be that the method is relatively inexpensive by using only one instrument, it is easy to conduct, and it takes less time than personal measurements. However, we have to acknowledge not only the strength and applicability but also the weaknesses of these instruments (Warrington and McLoughin, 2005). The mean personal noise measurement was higher compared to the area measurements, i.e. 92.0 versus 90.5 dB(A). One explanation might be that the area noise level corresponding to the work area for a job group was based on the unweighted mean of several points of measurements, while the worker within the job group could actually have spent more time in subareas with higher noise levels than the estimated mean area noise level. However, we did not track the movements of the workers to confirm this. Other studies in different workplaces have found an analogous difference between personal and area noise measurements, for example, in an iron and steel factory in India (130 versus 105 dB(A)) (Singh *et al.*, 2013), in the Swedish pulp mills study ((85.1 versus 83.6 dB(A)) (Neitzel *et al.*, 2016), and in a Norwegian Navy study (a difference of > 10 dB(A) among abroad frigates and Coast guard vessels) (Sunde *et al.*, 2015). Thus, area measurements may underestimate the actual noise exposure among workers, suggesting that a conservative approach should be taken using these data in risk assessment related to hearing loss. Nevertheless, this information is useful in planning for noise control and thus prevents development of noise-induced hearing loss.

Studies using area measurements have shown high noise levels comparable to those we have described; in a foundry in Egypt (range 82–94 dB(A)) (Kamal *et al.*, 1989), in the mill production area in Nigeria ((93 dB(A)) (Ologe *et al.*, 2006), in two factories in the Kingdom of Saudi Arabia (90.5 dB(A) and 95 dB(A)) (Noweir *et al.*, 2014) and in integrated iron and steel industry in India ((92–100 dB(A)) (Pandya and Dharmadhikari, 2002). In most of these studies, the measurements were taken close to the worker's head assuming that it represented the worker's noise exposure (Barrigón Morillas *et al.*, 2016). However, the wide range of tasks and processes in these factories present a challenge for the single fixed-point noise measurement to represent occupational noise exposure, and it is better to map the whole working area and describe the tasks done by workers to increase the validity of results. In addition, a stationary area noise measurement strategy has been recently found to have lower validity in occupational noise exposure compared to the personal noise measurement strategy, unless it is done in accordance to the ISO 9612:2009 (Neitzel *et al.*, 2016).

One strength of this study is that the personal noise measurements were performed over several days, with repeated measurements using high quality instruments. Inclusion of more factories could have strengthened the exposure models by distributing more than four factories into the subgroups of the respective determinants. More detailed assessment of tasks performed might have improved the models by explaining parts of the within-worker variability. On the other hand, the area noise measurement was done in only one day in each factory. However, the area measurements were assumed to be performed during stable working condition and should be representative for the work tasks done at the time. Our descriptions of factory buildings, noise sources, and the measured workers' noise exposure are important inputs in engineering noise control (Hansen and Goelzer, 2001). Furthermore, some of the variability in the individual measurement might be due to mechanical contact with the microphone during work (Sunde *et al.*, 2015), but its contribution should have minimal impact on the overall results when taking into account the generally high noise levels in the factories.

Future studies may be performed with task-based measurements of noise level, which will provide more detailed knowledge for work on noise reduction. We also recommend establishment of noise control measures including hearing conservation programme with compulsory periodic noise monitoring.

Iron and steel factories included in this study are likely to be representative of other factories in Tanzania and sub-Saharan Africa, as some of the factories not included in the present study have the same owners as the participating factories and may also share plant characteristics and technology. Because of these aspects, we believe that our findings can be generalized to iron and steel factories in Tanzania and other sub-Saharan Africa where the factories have similar characteristics.

Conclusion

This study found that most workers in the studied iron and steel factories were exposed to noise levels exceeding the OEL of 85 dB(A) and that they did not use hearing protection. This may result in hearing loss among workers. Furnace installation, billet weighing/transfer, and manual handling of raw materials/billets/crowbars were significant determinants in the furnace section while the size of the cutting machine, the steel billet weight and feeding re-heating furnace were significant determinants in the rolling mill section. Noise control measures based on identified determinants including hearing conservation programme are important in these factories.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

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Conflict of Interest

We declare that we have no conflict of interest.

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Article

Prevalence of Noise-Induced Hearing Loss Among Tanzanian Iron and Steel Workers: A Cross-Sectional Study

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Abstract: Iron and steel factory workers in Tanzania are likely to develop noise-induced hearing loss (NIHL) due to exposure to high sound levels. Studies on hearing status in this population are lacking. The aims of this study were to determine prevalence of NIHL among iron and steel workers and compare hearing thresholds at different frequencies with a control group. We conducted a cross-sectional study among 221 iron and steel workers exposed to average noise level of 92 dB(A), compared with 107 primary school teachers recruited as controls and exposed to average noise level of 79.7 dB(A). We used a questionnaire-based interview to collect information on socio demographic characteristics and other confounding variables. Hearing loss was defined as hearing threshold levels ≥25 dB hearing loss in either ear at 3000, 4000 or 6000 Hz. The prevalence of hearing loss was significantly higher among the exposed group than among the controls, i.e. 48% and 31%, respectively. There were significant differences in hearing thresholds between the exposed and control groups at 3000, 4000, 6000, and 8000 Hz. Hearing loss was more frequent among workers exposed to higher noise levels than among the controls suggesting that iron and steel workers run a higher risk of developing hearing loss.

Keywords: audiometry; occupational; noise-induced hearing loss; hearing threshold; exposed; iron and steel; Tanzania

1. Introduction

Noise-induced hearing loss (NIHL) is an underestimated public health concern [1,2]. Globally, the magnitude of disabling hearing loss (above 40 dB) from all causes has increased in the past two decades from 120 to 466 million people from 1995 to 2018 [3,4]. Estimates of the prevalence of hearing loss related to noise exposure above 85 dB(A) vary in the range of 7–21% or higher [5]. Prevalence is estimated to be higher in the low and middle-income countries compared to the findings in other parts of the world [4]. This may be due to ongoing economic investments in industrialization coupled with challenges related to an inadequate public health policy, lack of regulatory frameworks and limited resources spent on preventive measures.

Studies highlight noise exposure as one major risk factor contributing to hearing loss [1,4,5]. Other suggested risk factors for hearing loss include increasing age, [6–8] smoking, [5] exposure to organic solvents, [9] the use of ototoxic medicines, [5,9] gender, vibration, genetics, ear surgery, ear infections and illnesses [5,10]. In addition, exposure to noise has been associated with increased risks of cardiovascular diseases and diabetes [5,11–14].

Studies conducted in Sub-Saharan Africa (SSA) have mainly focused on the mining sector and indicate, for instance, that the prevalence of hearing loss in this industry was 37% in Zimbabwe and 47% in Tanzania [15,16]. Despite the presence of hearing conservation programmes aimed at prevention, the prevalence of hearing loss was above 50% among gold miners in South Africa, while it was 21% among stone crushers in Ghana [8,17]. To our knowledge, there are no published studies on hearing loss in large iron and steel factories in SSA. One study among iron and steel mill workers in Western Africa, specifically Nigeria, found a hearing loss prevalence of 28% and 57% in the better and the worse ears, respectively [18]. This prevalence is almost twice as high as that found in the general adult population in Uganda [10]. One must take into account that the definition and presentation of hearing loss may differ from study to study [1]. Nevertheless, the prevalence of hearing loss is still alarming.

In Tanzania, like in other SSA countries, investments in the manufacturing industries, including iron and steel industries, create jobs for a significant large number of employees. Globally the demand for steel is increasing, and this sector has provided employment for 50 million people [19]. The construction of new infrastructures such as bridges, flyover exchange roads, buildings, towers and railways obviously create numerous workplaces. Although the construction of industrial-level infrastructure represents significant increase in economic assets across SSA, little is known about the prevalence of NIHL in these industries, and documentation is scarce to inform policy-makers and stakeholders working in preventive health services. In a recent study, the eight-hour average noise level among iron and steel workers in Tanzania was 92 dB(A), and 90% of the measurements were above the occupational exposure limit of 85 dB(A). The workers did not use hearing protection devices [20] implying that the workers are at increased risk of developing NIHL. There is a need for assessing NIHL in this working group with a view to developing a plan for implementation of a hearing conservation programme. Therefore, the aims of this study were to determine the prevalence of NIHL among iron and steel workers, and to compare the hearing thresholds at different frequencies between these workers and a control group exposed to a low level of occupational noise.

2. Materials and Methods

2.1. Study Population

This cross-sectional study was conducted from June 2016 until June 2017 and involved permanent male workers from four iron and steel factories in Tanzania exposed to noise. Characteristics and details of noise-exposure assessments in these factories have been presented elsewhere [20]. The results showed a personal, mean equivalent noise exposure ($L_{EX,8h}$) for these workers of 92.0 dB(A) [20].

Controls were male teachers from 34 public primary schools in Tanzania. This control group was chosen because they were expected to be exposed to low levels of occupational noise [5,21–23]. In the control group, 24 full-shift noise measurements from six primary schools were conducted using personal dosimeters (type 4448, Brüel and Kjær, DK-2850 Nærum, Denmark) attached to the teacher's shoulder (ISO standard 9612:2009). The 8-hour equivalent noise exposure among these controls at work was 79.7 dB(A).

The sample size calculation was based on the estimated prevalence of hearing loss among workers exposed to loud noise at work. Since there was no available information about hearing loss among noise exposed workers or among the general population in Tanzania, the sample size was calculated based on a community baseline survey conducted in Uganda that found the prevalence of hearing loss among adults to be 12% [10]. In our study the effect of noise on hearing loss was hypothesized to be doubled i.e., 24%. To achieve 90% power and be able to detect a difference in hearing loss between noise exposed workers and a non-exposed group at a significance level of 0.05 (Using Open-Epi online calculator Version 3.3a, OpenEpi, Atlanta, GA, USA) [24], totally 230 exposed workers was needed. We added 10% to account for non-responders, providing a total sample size of 253 workers.

2.2. Study Participants

A total of 376 permanent workers (253 from four iron and steel factories and 123 teachers from 34 public primary schools) were randomly selected by using a table of random numbers from the provided list of workers and were invited to participate in the study (Figure 1). Workers list was provided by the respective employers. We held meetings with both the management for each factory and the administration at the public primary school where we presented the purpose of the project and asked for a research permit. Each of these partners referred us to a contact person who helped the research team in the planning of the research activities. The study participants were informed of the purpose of the project and those who agreed to participate, provided written consent. This paper presents the audiometry results.

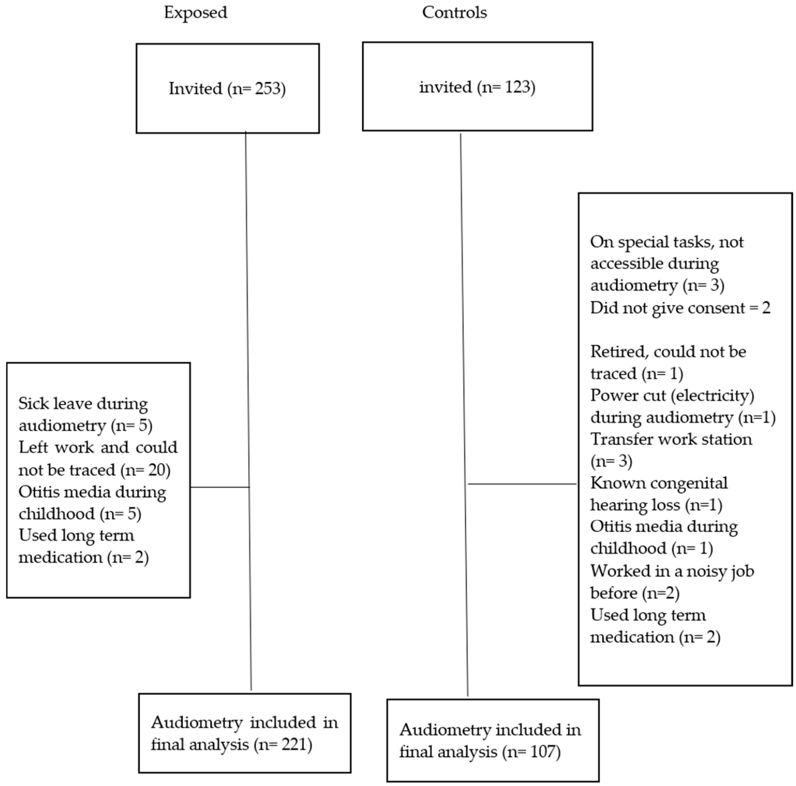

Figure 1. Flow chart describing the participants in the study of hearing loss among exposed iron and steel factory workers (n = 221) and controls—primary school teachers (n = 107) in Tanzania.

We used information collected through a structured interview with both exposed participants and controls to exclude the following categories of workers from the data analysis: those with congenital hearing loss, history of otitis media during childhood and those reported to have worked in noisy job among the controls. In addition, we excluded those who reported using long-term medication because the participants did not have adequate knowledge of the type of medication they used. Thus, we ended with a total of 328 (221 exposed and 107 controls) persons taking audiometric measurements (Figure 1).

The participants were instructed to avoid areas with high level of noise for a minimum of 12 h prior to audiometric examinations to minimize the possibility of temporary threshold shift (TTS). The duration since last occupational noise exposure (free noise exposure) was recorded before the audiometric test was administered [25,26].

2.3. Interview Questionnaire and Checklist

A structured interview questionnaire was used to collect information on demographic characteristics and factors that may influence hearing loss. These included age (in years), number of years of employment, history of noise exposure at work (yes/no), current smoking (yes/no), present use of long-term medication (yes/no), exposure to chemicals/organic solvents (yes/no), use of hearing protection while working in noisy areas (yes/no), ear infections as a child or adult (yes/no), head injury/trauma (yes/no), tinnitus (yes/no). In addition, information about otitis in childhood (yes/no), known congenital hearing loss (yes/no), any relatives with hearing loss and any history of ear-related medical condition (diabetes and hypertension) was collected. This information was collected before the audiometry day and used to exclude participants before audiometry (Figure 1).

Prior to otoscopy, but on the same day as the audiometry, participants were interviewed using a checklist indicating whether they had symptoms of upper respiratory infections (e.g., running nose) (yes/no), ear discharge (yes/no), time and date they left work (hours) and the most recent time they were exposed to high noise at a level that made it difficult to communicate. Afterwards, otoscopy was performed by an occupational physician; in circumstances when the ear canal was completely obstructed with wax or cerumen, the latter were removed, and a new appointment was scheduled for audiometry. This also applied to participants with upper respiratory infections; the test was postponed until they were asymptomatic.

2.4. Pure Tone Audiometry

Audiometric measurements (pure tone audiometry) were conducted in an ear-screening locally-constructed booth in a quiet room at the headquarters of the Occupational Safety and Health Authority (OSHA) in Tanzania. The same technical personnel conducted all audiometric tests using a standardized protocol. Background noise in the test booth was monitored by a calibrated hand-held Sound Level Meter (Brüel and Kjær, type 2250), and checked for conformity with ISO 8253-1:2010 standard [27]. The highest background noise level (L_{max}) in the booth was 51 dB at 31.5 Hz. For best results, audiometry was conducted in the morning before any work exposure. In addition, the city is less noisy in the morning compared to other times of the day when the participants could potentially be exposed to a higher level of environmental noise. Pure tone audiometry was conducted using an Interacoustics AD226 (Interacoustics, DK-5500, Middelfart, Denmark) with Amplivox Audiocup earphones having lower test limit of −10 dB. The equipment was pre-calibrated. Test frequencies were 250–8000 Hz in the order starting with 1000, 2000, 3000, 4000, 6000, 8000, 500, 250 and finish at 1000 Hz [27]. A manual test procedure was used in compliance with ISO 8253-1:2010 [26–28].

2.5. Data Analysis

Descriptive statistics were presented as mean and standard deviation or percentage. Chi-square and independent samples *t*-tests were used to compare categorical and continuous descriptive variables, respectively. NIHL was defined as hearing threshold level ≥25 dB hearing loss in either ear at 3000, 4000 or 6000 Hz [29].

Potential determinants of hearing loss were identified. Age was categorized into three age groups (tertiles) based on the age distribution among the controls. Duration of work was categorized arbitrarily into three groups (≤2 years, 2–10 years, 11–37 years). History of ear-related medical conditions (diabetes, hypertension, ear infections and head injury) was combined into a dichotomized variable (yes/no), current smoking (yes/no), relatives with hearing impairment (yes/no), tinnitus (yes/no) and previous noisy work (yes/no). A chi-square test was used to explore the relationship between these variables and hearing loss in exposed participants compared with controls.

The intercorrelation between participant's age and duration of work determinants was tested with the Pearson correlation test. In multiple regression analyses, we chose the determinant that contributed most to the hearing loss.

We used log binomial regression models with a 95% confidence interval (CI) to ascertain differences in hearing loss (yes/no) between exposed and controls within each age strata and within the total group of workers while adjusting for the significant determinants selected from Chi-square analyses and the correlation test.

We computed the mean hearing threshold for the different test frequencies for both exposed participants and controls, as well as for the three age groups within the main exposure groups. For each test frequency, multiple linear regression was used to analyze for differences between exposed and controls, while adjusting for age as a continuous variable, previous noisy work and history of ear-related medical condition.

The exposed group had a mean exposure duration of 5 years (range: 0–24 years) and a L_{Aeq8h} of 92 dB(A) [20]. Within the three age groups (≤2 years, 2–10 years, 11–37 years) the mean duration of exposure in these factories were 1, 5, and 17 years, respectively. We calculated the predicted noise-induced permanent threshold shift (NIPTS) corresponding to these three mean exposure durations according to ISO 1999 section 6.3, that provides a formula and method that predicts NIPTS at 1000, 2000, 3000, 4000 and 6000 Hz as a function of the logarithm of exposure duration (*d*) (in years), and the square of noise exposure level (L_{Aeq8h}), with frequency specific constants *u*, *v*, and L_0 (a sound pressure level, defined as a function of a given constant value for each frequency in decibels [30]:

$$\mathrm{NIPTS} = [u + v\log_{10}(d)]\,(L_{Aeq8h} - L_0)^2 \quad (1)$$

We used IBM SPSS Statistics, Version 25 (Allen & Unwin, 83 Alexander Street, Crown Nest, NSW, Australia) for data analysis and set a parameter of $p < 0.05$ as statistical significance. NIPTS was estimated using Microsoft Excel (Office 365, Microsoft Corporation, Redmond, WA, USA).

2.6. Ethical Clearance

We obtained ethical clearance from The Regional Committee of Medical and Health Research Ethics (REK-VEST) in Norway (number 2016/635/REK sør-øst dated 20 May 2016); and later from The Muhimbili University of Health and Allied Sciences (MUHAS) Ethics Committee in Tanzania number 2016-06-24/AEC/Vol. XI/38 dated 24 June 2016. Each iron and steel factory and primary school administration was contacted individually, and all of them granted permission to conduct the study. Individual participants were contacted and informed about the research objectives and activities to be conducted and gave written consent. Information that was collected was treated as confidential and was not accessed by unauthorized parties. We used participants' identification instead of names in data collection, processing and analysis.

3. Results

The participation rate was 87% for both the exposed and controls. The exposed group was significantly younger than the controls (independent sample *t*-test; $p < 0.001$) (Table 1). There was a significant difference between exposed and controls for the three descriptive variables; age group, duration of work and previous noisy work, (Chi square test; $p < 0.001$) but not for the other variables i.e., current smoking, tinnitus, relative with hearing impairment and history of ear-related medical condition (Table 1). Among the exposed, 67% of the workers fell in the youngest age group (18–35 years) (Table 1). In addition, there were significant differences in hearing loss between exposed and controls for the four determinants—age group, duration of work, previous noisy work and history of ear-related medical condition (Chi-square test; $p < 0.05$). The overall prevalence of hearing loss was significantly higher (Chi square test, $p = 0.003$) among exposed workers (48%) than among the controls (31%) (Table 2).

Table 1. Descriptive characteristics of the participants in the study among noise-exposed ($n = 221$) and control ($n = 107$) workers in Tanzania.

Characteristics	Descriptive		*p*-Value
	Exposed (*n* (%))	Controls (*n* (%))	
Age: Mean (SD)	32 (8)	40 (7)	<0.001 [a]
Age group (years) (group mean for Exposed))			
18–35 (27)	149 (67.4)	36 (33.6)	<0.001 [b]
36–43 (39)	58 (26.2)	37 (34.6)	
44–59 (47)	14 (6.3)	34 (31.8)	
Total	221 (100.0)	107 (100.0)	
Duration of work (years) (group mean for Exposed)			
≤2 (1)	86 (38.9)	-	<0.001 [b]
3–10 (5)	108 (48.9)	27 (25.2)	
11–37 (17)	27 (12.2)	80 (74.8)	
Current smoking			
no	183 (82.8)	96 (89.7)	
yes	38 (17.2)	11 (10.3)	0.07
Previous noisy work			
no	178 (80.5)	107 (100.0)	
yes	43 (19.5)	-	<0.001 [b]
Tinnitus			
no	202 (91.4)	104 (97.2)	
yes	19 (8.6)	3 (2.8)	0.06
Relative with hearing impairment			
no	199 (90.0)	96 (89.7)	
yes	22 (10.0)	11 (10.3)	0.9
History of ear-related medical condition			
no	176 (79.6)	93 (86.9)	
yes	45 (20.4)	14 (13.1)	0.01 [b]

[a] independent samples *t*-test; [b] Chi-square test.

Table 2. Prevalence of hearing loss among exposed ($n = 221$) and control ($n = 107$) workers in Tanzania.

Variable	Hearing Loss [a] (*n* (%))			
	Exposed	Controls	Chi-Square Test (*p*-Value)	Prevalence Ratio 95% Confidence Interval) [†]
Age group (years)				
18–35	63 (42.3)	5 (13.9)	0.002 *	2.5 (0.93, 6.76)
36–43	34 (58.6)	12 (32.4)	0.013 *	1.7 (0.79, 3.47)
44–59	10 (71.4)	16 (47.0)	0.124	1.5 (0.58, 3.70)
All	107 (48.4)	33 (30.8)		1.3 (1.10, 1.62)

[a] Hearing loss defined as ≥25 dB in either ear at 3000, 4000 or 6000 Hz; [†] log-binomial analysis within each age group, adjusted for age as a continuous variable, previous noisy work and history of ear-related medical condition; * $p < 0.05$.

Hearing loss increased with advancing age among both exposed and controls (Table 2). Within the age-groups, there were significant differences in hearing loss between exposed and the controls for the youngest and middle-aged group (Chi square test, $p\ 1 = 0.002$; $p\ 2 = 0.013$) but not for the older age group (Table 2).

Results from the log binomial regression model, adjusted for age, previous noisy work and history of ear-related medical condition, showed a statistically higher risk of hearing loss among exposed workers compared to controls, with a prevalence ratio of 1.3. When performing the analysis within each age stratum, the youngest age group (18–35 years) had the highest prevalence ratio (2.5), although it was not statistically significant (Table 2).

The mean hearing threshold between exposed and control workers at 3000, 4000 and 6000 Hz differed significantly (independent samples t-test, $p < 0.05$) (Table 3). In linear regression analyses within each age stratum, there were significant differences in hearing threshold between exposed and controls for the frequencies 4000 and 6000 Hz within the youngest age group (18–35 years) adjusting for age as a continuous variable, previous noisy work and history of ear-related medical condition (Figure 2). In analogous analyses, the hearing threshold for the frequencies 3000, 4000 and 6000 Hz were significantly different in the 36–43 years age group, and in the age group 44–59 years, only the frequency 6000 Hz was significantly different (Figure 2).

Table 3. Hearing threshold of the worse ear among noise exposed and controls for the tested frequencies.

Workers' Group	Number of Workers	Mean Hearing Thresholds in Decibel (dB) for Each Frequency							
		250	500	1000	2000	3000	4000	6000	8000
Exposed	221	17.0 (6.1)	19.0 (5.2)	19.4 (6.0)	19.6 (7.3)	23.6 (8.9) [a]	25.0 (9.7) [a]	24.3 (10.6) [a]	16.0 (9.7) [a]
Control	107	17.2 (5.5)	18.0 (5.7)	19.7 (5.2)	18.8 (8.1)	20.8 (8.0)	21.7 (8.8)	19.6 (9.2)	13.6 (9.8)

[a] independent samples t-test, $p < 0.05$.

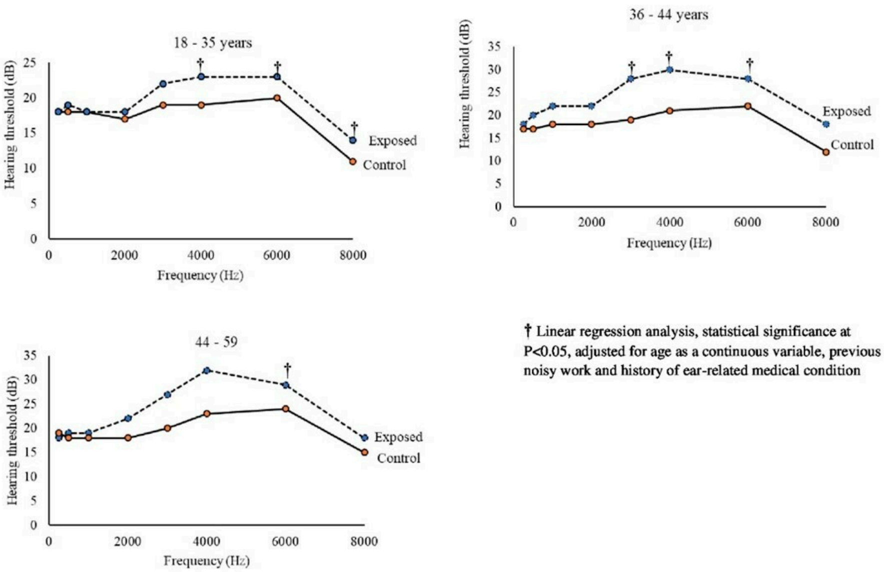

Figure 2. Hearing threshold of noise-exposed male workers (n = 221) (dotted lines) compared with male controls (n = 107) (solid lines) in Tanzania, stratified into age groups (triplets).

Table 4 shows the age-stratified differences in hearing thresholds for the different test frequencies in exposed and controls. The regression coefficients show that for the frequencies with significant findings, the difference between exposed and controls was about 3–6 dB among the youngest age group, 4–6 dB in the middle-aged group and about 10 dB for the oldest age group.

Table 4. Hearing threshold at the tested frequencies stratified by age groups among exposed iron and steel factory workers (n = 221) and controls (n = 107) in Tanzania.

Age Group	Audiometry Frequency (Hz)													
	250		500		1000		3000		4000		6000		8000	
	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI
18–35	0.16	−2.31, 2.63	−1.54	−3.47, 0.39	−0.53	−2.57, 1.52	−3.05	−6.19, 0.11	−4.94 *	−8.57, −1.31	−5.84 *	−10.16, −1.52	−4.90 *	−8.66, −1.14
36–43	−0.14	−3.06, 2.77	−1.92	−4.63, 0.79	−1.45	−4.54, 1.64	−5.70 *	−10.11, −2.27	−6.37 *	−10.93, −1.81	−4.32 *	−8.73, 0.09	−3.36	−7.51, 0.79
44–59	−0.72	−5.51, 4.07	−2.47	−6.52, 1.59	−1.07	0.67, −6.20	−6.85	−14.66, 0.95	−4.95	−13.23, 3.33	−10.22 *	−18.87, −1.58	−6.00	−15.41, 3.41

Linear regression analysis, adjusted for age as a continuous variable, previous noisy work and history of ear-related medical condition. * Statistical significant at $p < 0.05$.

The mean hearing threshold among the participants in the 18–35 age group was similar to the predicted NIPTS according to ISO 1999 at the lower frequencies (1000, 2000 and 3000 Hz), while it was about 1 dB higher than ISO 1999 for the higher frequencies (4000 and 6000 Hz) (Figure 3a). For the 36–44 and 45–59 age groups, the hearing threshold for the higher frequencies were lower (3, 1 dB and 6, 4dB lower, respectively) for same frequencies than that the NIPTS predicted by ISO 1999 (Figure 3b,c).

Figure 3. (**a**–**c**) Mean of the measured hearing threshold by audiometry (dotted lines) and median noise-induced permanent threshold shift (NIPTS) predicted by ISO 1999 (solid lines) for the three age-groups of iron and steel workers in Tanzania exposed to an average noise level of L_{Aeq8h} of 92 dB(A) for the mean duration of noise exposure within each age group.

4. Discussion

We found a higher prevalence of hearing loss among Tanzanian iron and steel factory workers compared to controls i.e., 48% vs. 31% respectively. In addition, a comparison of hearing thresholds between the two groups for the frequencies 4000 and 6000Hz revealed significant differences. To our knowledge, this is the first study in SSA to document the prevalence of hearing loss among workers exposed to noise in iron and steel factories.

In the present study, we found a significantly higher prevalence of NIHL among iron and steel workers than the controls. The noise exposed workers were exposed to a mean noise level of 92 dB(A), without using hearing protection devices [20]. At this noise level, it is likely that the workers develop NIHL [31,32]. A study conducted among Indian iron and steel workers exposed to noise levels above 90 dB(A) found an even higher prevalence of NIHL than we found. Over 90% of the workers engaged in casting and forging had hearing loss in the higher frequencies i.e., 4000 and 6000 Hz [33]. This is likely due to differences in the nature of work, including tasks and tools used during the steel production process. For example, the Indian study was done in small and medium factories with the forging and casting tasks frequently characterized by impulse noise that might cause hearing damage at higher frequencies [34]. By contrast, our study was done in larger-scale factories with a relatively higher level of mechanization. Another study done in Nigeria also found higher prevalence in the worse ear

(57%) among steel mill workers exposed to 75–93 dB(A), with pure tone averages of 30 dB, 31 dB and 32 dB for the finishing, mill floor and mechanical departments respectively, as compared to a pure tone average of 21 dB among administrative workers with lower noise exposure (49 dB(A)) [18]. In Nepal, the prevalence among workers in a steel factory was comparable to our study, i.e., 40% and 46% for the right and left ear, respectively. However, the study excluded workers over 45 years and information on factory characteristics were not available [35]. Another study done in Nepal among 115 small-scale metal industry workers and 123 controls found lower prevalence for the exposed (30%) and only 4% for the controls [36]. The difference in prevalence between the Nepal study and our study may be due to the definition used to define hearing loss [1,36]. However, the high prevalence presented based on these studies suggests that noise exposure among iron and steel workers contribute substantially to hearing loss [37].

Age is one of the main factors for the development of hearing loss. To adjust for age can be difficult in statistical analyses. In the present study, we stratified the working population into three age groups and found a borderline increased risk for hearing loss among the younger age group (18–35 years), and significant differences between exposed and controls in hearing thresholds for the frequencies of 4000 and 6000Hz. The significant difference in the dip for the 4000 and 6000 Hz frequencies is a sign indicating hearing loss due to noise exposure in this age stratum [17,18,38,39]. Similar findings have been shown among gold miners in South Africa where the greatest difference in hearing threshold between age strata was found among the younger age group (16–40 years) at the noise dip of 4000 Hz [7]. Therefore, it is essential that noise control measures, including hearing conservation programmes should be established particularly to protect workers from developing NIHL.

In this study we found higher estimates of NIPTS than predicted by ISO 1999 standard for 18–35 years at frequencies of 4000 and 6000 Hz. These frequencies are likely to be affected by noise exposure [40]. The characteristics of noise, size of ear canal and other factors determines the location of notch for the higher frequencies [41]. However, the notch at these frequencies and especially at 4000 Hz is an established clinical sign and may be valuable in confirming the diagnosis of NIHL [40,42]. In addition, Our NIPTS estimates, though generally lower than that of ISO 1999 predictions, show similar patterns especially at higher frequencies. This result differs from a study conducted in United States which reported estimates in agreements to that of ISO 1999 [43]. The lower results and estimates from our study may be explained partly by differences in reference population characteristics. ISO 1999 standard was prepared based on populations from developed and industrialized countries such as United States and with steady state noise [30], which it is difficult to compare results to our study that had mixed noise characteristics. However, although the hearing threshold in the age range 44–59 years was somewhat lower than predicted from the ISO 1999, the overall results suggests that noise exposure among the iron and steel workers leads to an increased risk of NIPTS.

The control group in our study had a significant lower prevalence of hearing loss compared to the exposed workers at higher frequencies. The measured hearing loss in this group was lower than that recorded among the controls in South African miners study for the higher test frequencies i.e., 31% versus 46% respectively [8]. The control group in the South Africa study was the administration group, and this makes it difficult to compare with our study. Moreover, the control group in the South Africa study was not screened for previous noise exposure as we did in our study. The participants in our control group were screened for several factors responsible for hearing loss and were thus expected to have low prevalence. This indicates that there might be factors other than noise that may have contributed to the hearing loss in the South African study. In Tanzania, there are no published data on community hearing profile among adults. Community studies conducted in other African countries such as Nigeria and Egypt found a lower prevalence of hearing loss (defined as hearing threshold >25 dB) than we found i.e., 18% and 16%, respectively [44]. However, in these community studies, there is no information on noise exposure profile among the participants, and this makes it difficult to compare with the control group in our study. Based on the selection of examined workers, including the control group, we think that it is likely that occupational noise exposure has contributed to the difference in hearing loss between our two groups.

Strengths of this study are the high response rate among the participants, the use of a control group from workplaces with low sound levels, and the use of standardized methods for audiometry. In addition, it was possible to control for the effect of age in hearing thresholds by stratification of age groups while adjusting for age as a continuous variable within the age strata. The statistical analyses made it possible to adjust for potential confounding factors related to hearing loss, such as current smoking, previous noise exposure, tinnitus, history of ear-related medical conditions, duration of work and relatives with hearing impairments. The use of calibrated research equipment and devices together with adherence to the novel procedure related to audiometry testing and ISO 8253-1:2010 standard for ambient noise improved the findings.

Our study had some limitations; The design of the study was cross-sectional, and this reduces the possibility to conclude regarding the causal relationship between noise at work and hearing loss. Still, this study indicates that the sound levels are of importance to the registered hearing losses in this working population, as the frequencies involved are in the upper frequency area and the sound levels measured were above 85 dB(A). A longitudinal study would have provided a better exposure-effect association. Information collected through interview questionnaire might introduced recall bias. To minimize this bias, we used the same trained research personnel and method for both the exposed and the controls. In addition, in many societies today, people listen to music at high volume levels, and this may affect their hearing ability. We have limited information about leisure time exposure to noise among our study participants, but we have no reason to believe that the workers in iron and steel factories are more exposed to leisure time sound than are the control workers. In addition, iron and steel workers spent most of their time during the day at work. Lastly, it was impractical to monitor workers at their homes before audiometry.

5. Conclusions

Based on these findings, this study should be a wake-up call for stakeholders in the establishment and should serve to encourage the implementation of noise control measures such as the use of hearing protection devices in these workplaces. The information we found on the high prevalence of hearing loss may be used by policy and decision-makers in awareness creation programmes aimed at noise control such as establishing hearing conservation programmes and preventive services among working populations exposed to noise [33].

Author Contributions: I.P.N., B.E.M., M.B. and A.M.T. were involved in project conceptualization, methodology, validation, formal analysis, data curation, writing (original draft preparation), writing (review and editing) and visualization. I.P.N., J.A.H. and A.M.T. were involved in investigation. In addition, B.E.M. and M.B. were involved in resources, supervision and project administration.

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Occupational noise exposure and hearing loss: A study of knowledge, attitude and practice among Tanzanian iron and steel workers

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Occupational noise exposure and hearing loss: A study of knowledge, attitude and practice among Tanzanian iron and steel workers

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ABSTRACT

We assessed Knowledge Attitude and Practice (KAP) regarding occupational noise exposure, Noise-induced hearing loss, audiometry and use of hearing protection devices among iron and steel factory workers exposed to high noise level. A modified, validated, structured questionnaire was used to collect information from 253 male workers randomly selected from the four factories. The sum scores for each domain of KAP were computed. Scores above 75% were defined as good knowledge and positive attitude. For practice, scores of >50% were defined as good. Independent samples *t*-test and Chi-squared test were used to analyze association between KAP and continuous/categorical variables respectively. Majority of workers displayed poor knowledge and poor practice (94%), but 76% displayed a positive attitude. Most of the workers (86%) had never been provided with hearing protection devices. The mean scores for attitude and practice differed significantly between the four factories (one-way ANOVA, $p < 0.001$). Implementation of hearing conservation program with provision of hearing protection devices are suggested.

KEYWORDS

Hearing conservation program; hearing protection devices; iron and steel factory; knowledge; noise exposure; noise-induced hearing loss; worker health

Introduction

Noise-induced hearing loss (NIHL) is a public health problem[1] that has been increasing in developing countries (including Tanzania), as compared with other parts of the world.[2] The estimated prevalence of NIHL in studies in the field of mining and in iron and steel factories in Tanzania was 47% and 48% respectively,[3,4] which is above the average global prevalence of NIHL, that ranges from 7%–21%.[5] A high prevalence of NIHL has been linked to increased industrialization coupled with governing institutions' low capacity for provision of adequate preventive measures against noise, effective programs to prevent NIHL,[6,7] poor data collection systems[8,9] and limited research to document the magnitude of the problem.[2] In addition, the coverage of occupational health services in the working population has been low,[7,10] and this might in turn have affected workers' knowledge of occupational noise exposure and prevention of hearing loss.

NIHL (with a permanent threshold shift) is irreversible once it has occurred, thus effective preventive solutions are necessary.[11] Various noise-control measures exist, namely engineering control (elimination, substitution, targeting of noise-source manipulation), administrative control (changing work practices and schedules, policy-making and enforcing regulations that target workers' behavior) and use of personal protective equipment (PPE) to protect individual workers, with regular surveillance.[12,13] Evaluation of the effectiveness of the interventions implemented has yielded varied results.[14] Nevertheless, studies suggest that a comprehensive hearing conservation program, including provision and use of hearing protection devices (HPDs), may be effective, even when administrative and engineering methods of noise control are not feasible,[15,16] and such intervention has been found to be associated with less NIHL.[17] In countries with limited resources like Tanzania it would be feasible to advocate establishment and implementation of hearing conservation programs. To achieve this, it is necessary to establish and document workers' Knowledge, Attitude and Practice (KAP) as a prerequisite for

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effective planning of interventions. This study is thus being conducted to document the level of KAP in iron and steel workers.

There are interactions between various aspects of individuals' knowledge of health and their attitude to it that may affect practices at work.[18] A high prevalence of NIHL has been associated with a low level of KAP in workers. For example, a cross-sectional study of 97 Malaysian quarry workers found a high prevalence of NIHL (57%), while the KAP scores were low, i.e. 11% for knowledge, 10% for attitude and 28% for practice.[19] Other KAP studies have documented varying results about KAP. Two studies, one in Malaysia and the other in Nigeria, found good knowledge, a positive attitude but poor practice among workers.[20,21] In addition, two other studies in Nigeria have reported good knowledge with poor practice.[22,23]

Practice can also be influenced by factors such as non-availability of hearing protection devices, high financial costs, poorly fitting of hearing protection devices, and maintenance, though regular training and supervision improve usage.[20,21,23,24] Also, KAP scores differ among workers in different sectors, necessitating the documentation of sectoral related findings for effective planning and implementation of preventive interventions.

Our recent findings show that workers in the iron and steel factories in Tanzania were exposed to personal mean equivalent noise exposure ($L_{EX,8h}$) of 92.0 dB (A).[3] Several processes contributed to the recorded sound level such as various operating machines, manual handling of metal scraps and steel billets and feeding metal scraps into furnace.[3] The prevalence of NIHL in these workers was 48%,[25] suggesting an urgent need for effective noise-control intervention. To our knowledge, there is no published information from iron and steel factories in Tanzania that would inform policy and decision makers and might be useful in the formulation and implementation of preventive measures seeking to improve the situation of workers. The purpose of this study was thus to assess KAP in iron and steel factory workers in Tanzania exposed to a high level of noise.

Materials and methods

Study population

We conducted a cross-sectional study of 253 randomly selected male participants working in steel-bar production lines in four iron and steel factories in Dar es Salaam, Tanzania between June 2016 and June 2017. The main study also comprised audiometry to examine hearing loss among the workers and measurement of noise exposure in the factories. The details of noise levels and the characteristics of the studied factories are presented elsewhere.[3]

The sample size calculation was based on the estimated prevalence of hearing loss among workers exposed to loud noise at work. Since there was no available information about hearing loss among noise exposed workers or among the general population in Tanzania, the sample size was calculated based on a community baseline survey conducted in Uganda that found the prevalence of hearing loss among adults to be 12%.[26] In our study the effect of noise on hearing loss was hypothesized to be doubled i.e. 24%. To achieve 90% power and be able to detect a difference in hearing loss between noise exposed workers and a non-exposed group at a significance level of 0.05 (Using Open-Epi online calculator Version 3.3a),[27] totally 230 exposed workers was needed. We added 10% to account for non-responders, providing total sample size of 253 workers.

Study participants

The research team held meetings with the management of each factory, explained the purpose of the research and requested permission to conduct the project. All four factories agreed to participate. The managements of these factories each assigned a contact personnel to help the research team with the planning and implementation of the research activities. We included permanent production line workers who consented to participate and excluded workers in other sections without occupational noise exposure. A list of permanent workers was provided, and 253 workers were randomly selected from a total of 588 production workers of four factories. These workers were contacted and informed about the project objectives and were required to give written consent. All workers selected agreed to participate in the project. This study was ethically cleared by Ethical committees in Norway and Tanzania and all workers participated gave informed consent prior to their inclusion into the study.

Interview questionnaire

A modified, validated, structured KAP questionnaire from a study of Malaysian sawmill workers was used to collect information from 253 workers through an interview.[20,28] This Malaysian questionnaire was modified to suit the local context, e.g. the statement in the knowledge-assessment part asking for hobbies was modified to omit the word 'scuba', adding 'listening to loud music for long time'. A statement involving specific legislation in Malaysia was modified and remained as a neutral statement unrelated to any country. The word 'sawmill' was omitted, and the word 'deafness' was translated into 'hearing loss' (HL). The English version of the questionnaire was translated into Swahili and then back into English **once** to check for logical consistency and meaning. No changes were made after translation.

Workers' knowledge regarding NIHL was assessed using 18 statements, each with a score of '1' for correct response and a maximum score of 18 points, equivalent to 100%. The 18 statements in the knowledge domain were for collection of information on the causes, symptoms, treatment and prevention of NIHL.

Workers' attitudes to the importance of noise reduction at the workplace, NIHL, audiometry and wearing of hearing protection devices were assessed by 13 statements, using a five-point scale ranging from 'strongly disagree', 'disagree' and 'neither disagree or agree' to 'agree' and 'strongly agree', each with a corresponding score of between one and five. The maximum score was 65 points, equivalent to 100%.

Workers' practice regarding provision and use of hearing protection devices, health and safety training and audiometry were assessed using 12 statements with the three possible responses 'always', 'sometimes' and 'never', and with scores of 3, 2 and 1, respectively. The maximum score was 36 points, equivalent to 100%.

Information regarding participants' socio-demographics, i.e. age in years, duration of work (in years) and educational level (no formal education, primary education, secondary and tertiary education) was also collected. All information was collected by a research assistant trained for the study.

Data analysis

Descriptive statistics were presented as means and standard deviation for continuous variables and frequencies or percentages for categorical variables.

The variable age in years was categorized as tertiles, with almost equal percentages of participants. Duration of work was arbitrarily categorized in accordance with three groups ($\leq$2 years, 3–10 years, 11–24 years). The educational-level variable was dichotomized (primary education = 0 vs secondary and tertiary education = 1), as there were no participants without any formal education.

The sum scores for the KAP domains were computed, converted into percentages of the total score and then dichotomized, with knowledge and attitude scores of $\geq$75% being defined as good knowledge and positive attitude, respectively,[20] whilst the practice score of $\geq$50% was defined as good practice.

In the sum scores for KAP, the differences between age and duration of work were explored using one-way Analysis of Variance (ANOVA), whilst an independent samples t-test was used to analyze the association between KAP and the continuous variables, i.e. age, duration of work and educational level. Chi-squared test was used to analyze the association between dichotomized KAP and categorical variables, i.e. age group, duration of work and educational level. Two multiple linear regression analysis was used to explore the relationship between attitude and practice scores as dependent variables, respectively and the significant variables from the preliminary analyses, i.e. educational level and the factory. In this analysis, three dummy variables were used for factory B, factory C and factory D. Factory A was used as reference.

Internal consistency in distinct items in each domain of knowledge, attitude and practice was evaluated using Cronbach's Alpha coefficient (α), the results being $\alpha = 0.74$, 0.70 and 0.72, respectively.

The IBM SPSS statistics, Version 25 was used for data analysis and a parameter of $p < 0.05$ was set as statistical significance.

Ethical consideration

This study was completed in accordance with the Helsinki Declaration of 1975 and its subsequent revisions. The ethical clearance for this study was issued by The Regional Committee of Medical and Health Research Ethics (REK-VEST) in Norway number 2016/635/REK sør-øst dated 20th May 2016; and The Muhimbili University of Health and Allied Sciences (MUHAS) Ethics Committee in Tanzania with Institutional Review Board (IRB) number 2016-06-24/AEC/Vol. XI/38 dated 24th June 2016. Permission to conduct the study was granted by each iron and steel factory. The information collected was treated as confidential. Each individual participant was contacted and informed about the research objectives and activities to be conducted and gave written consent prior to inclusion into the study.

Table 1. Descriptive characteristics of the participants and their association with KAP in the study among Tanzanian iron and steel workers ($N = 253$).

Descriptive		KAP distribution					
		Knowledge[†]		Attitude[‡]		Practice[§]	
Variable	Frequency (%)	Good [n (%)]	Mean score [mean (SD)]	Positive [n (%)]	Mean score [mean (SD)]	Good [n (%)]	Mean score [mean (SD)]
Age: Mean (*SD*)	32 (8)						
Factory identification							
Factory A	71 (28.1)	8 (11.3)	9.1 (3.3)	27 (38.0)	48.5 (9.2)[††]	5 (7.0)	13.8 (2.1)[††]
Factory B	57 (22.5)	4 (7.0)	9.5 (2.9)	52 (91.2)	57.1 (4.5)	3 (5.3)	13.6 (1.8)
Factory C	61 (24.1)	7 (11.5)	9.0 (3.1)	51 (83.6)	56.2 (6.1)	7 (11.5)	13.9 (3.3)
Factory D	64 (25.3)	4 (6.3)	9.0 (3.2)	61 (95.3)	58.5 (5.1)	0	12.1 (0.2)
Total	253 (100.0)	23 (9.1)	9.1 (3.1)	191 (75.5)	54.8 (7.7)	15 (5.9)	13.3 (2.3)
Age group (years)							
18–27	89 (35.2)	11 (12.4)	9.0 (3.4)	61 (68.5)	53.9 (8.3)	7 (7.9)	13.5 (2.7)
28–35	84 (33.2)	7 (8.3)	9.3 (3.1)	63 (75.0)	54.6 (7.9)	3 (3.6)	13.0 (2.0)
36–64	80 (31.6)	5 (6.3)	9.0 (2.9)	67 (83.8)	56.1 (6.7)	5 (6.3)	13.4 (1.9)
Duration of work (years)							
≤2	105 (41.5)	10 (9.5)	9.2 (3.1)	79 (75.2)	55.0 (8.0)	7 (6.7)	13.2 (2.1)
3–10	117 (46.2)	12 (10.3)	9.0 (3.3)	87 (74.4)	54.6 (7.9)	6 (5.1)	13.3 (2.5)
11–37	31 (12.3)	1 (3.2)	9.0 (2.4)	25 (80.6)	55.8 (6.1)	2 (6.5)	13.8 (2.0)
Education level							
Primary education	169 (66.8)	16 (9.5)	9.2 (3.0)	136 (80.5)[¶]	55.7 (6.9)[#]	7 (4.1)	13.1 (1.8)[#]
Secondary and tertiary education	84 (33.2)	7 (8.3)	9.0 (3.4)	55 (65.5)	53.0 (8.9)	8 (9.5)	13.8 (2.9)

[†]Knowledge score (as a percentage) categorized as Good (≥75%/poor < 75%); [‡]attitude score (as a percentage) categorized as positive (≥75%/negative < 75%).
[§]practice score (as a percentage) categorized as Good (≥50%/poor < 50%); [¶]Chi-square test, statistically significant at $p < 0.05$.
[#]independent samples t-test, statistically significant at $p < 0.05$.
[††]One-way analysis of variance (ANOVA) with Post-hoc Turkey HSD test, statistically significant at $p < 0.05$.

Results

The participants' mean age (in years) was 32 (range: 18-64), and 68% of them were under 35. The mean age for Factory A was 29 ($SD = 6$), for Factory B 36 (9), for Factory C 29 (8) and for Factory D 33 (7). Sixty-seven per cent had received primary education, 33% had received secondary and tertiary education and 88% had worked for 3 to 10 years (Table 1). The participation was 100%.

The mean scores for attitude and practice differed significantly between the four factories (one-way ANOVA, $p < 0.001$) (Table 1). Factory A had a significantly lower mean attitude score than the other three factories, whilst there was no significant difference between those other three factories. The mean practice score for Factory D was significantly lower than for the other three factories (A, B and C), whilst there was no significant difference in mean practice scores between those three factories. The mean knowledge scores did not differ between any of the four factories (one-way ANOVA, $p > 0.05$).

Overall the mean score for knowledge did not differ significantly between the subgroups for age, duration of work and educational level (Table 1). Only 23% of participants had a good knowledge (score ≥ 75%) of occupational noise-exposure hearing loss (Table 1).

Table 2. Determinants for attitude and practice in a KAP study among 253 iron and steel factory workers in Tanzania.

Determinant	Attitude		Practice	
	β	95%, CI	*β*	95%, CI
Factory identification				
Factory A	Ref.		Ref.	
Factory B	12.91*	11.89, 13.93	−0.10	−0.70, 0.49
Factory C	11.71*	10.75, 12.68	0.35	−0.21, 0.91
Factory D	15.19*	14.22, 16.16	−4.39*	−4.96, −3.83
Education level				
Primary education	Ref.		Ref.	
Secondary and tertiary education	−0.94*	−1.71, −0.17	1.33*	0.88, 1.78

*Multiple linear regression, statistical significant at $p < 0.05$.

There was a significant difference in attitude scores between participants who had received primary education and those who had received secondary and tertiary education (independent samples t-test, $p = 0.01$) (Table 1). The participants who had received primary education had a significantly more positive attitude than those who had received secondary and tertiary education (chi-square test, $p < 0.05$) (Table 1). In the practice domain, participants who had received primary education had significantly lower scores than their counterparts (independent samples t-test, $p = 0.03$) (Table 1). The overall mean scores for practice was low (Table 1).

In the multiple linear regression model for the attitude domain, factory B, factory C and factory D had

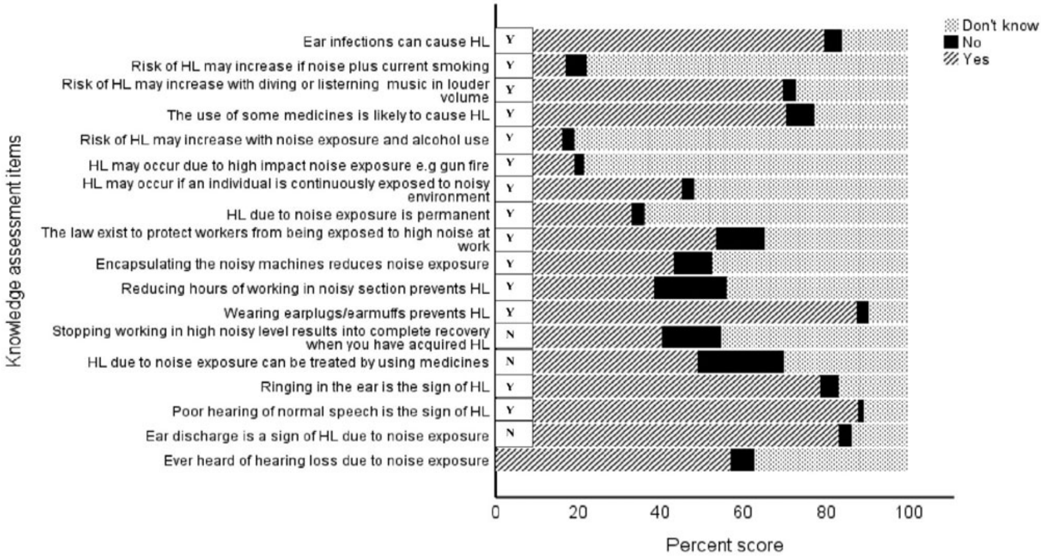

Figure 1. Knowledge score (as a percentage) regarding noise-induced hearing loss (NIHL) (causes, symptoms, treatment and prevention) for various items in 253 iron and steel workers in Tanzania. The correct answer for each item is indicated by Y = yes and N = no.

higher scores than factory A, while secondary/tertiary education was associated with lower score than primary education. This regression model explained 28% of the total variance in attitude score (Table 2).

For the practice domain, factory D had lower score than factory A (reference), while secondary/tertiary education was associated with higher score than primary education (Table 2). These two determinants (educational level and factory D) explained 12% of the total variance in practice.

A high proportion of the participants had a poor overall knowledge of the specific causes of NIHL (Figure 1). For example, only 16% responded correctly to the statement 'HL may occur due to high-impact noise exposure, e.g. gunfire, and 45% to the statement 'HL may occur if an individual is continuously exposed to a noisy environment'. Regarding NIHL symptoms, 88% responded correctly to the statement 'Poor hearing of normal speech is a sign of HL' and 79% to the statement 'Ringing in the ear is the sign of HL'. Nevertheless, only 33% responded correctly to the statement 'HL due to noise exposure is permanent', 21% to the statement 'HL due to noise exposure can be treated by using medicines' and only 14% to the statement 'Stopping working in high noise level results into complete recovery when you have acquired HL' (Figure 1). With regard to prevention, 87% responded correctly to the statement 'Wearing earplugs/earmuffs prevents HL', 43% to the statement 'Encapsulating the noisy machines reduces noise exposure', 38% to the statement 'Reducing hours of working in a noisy section prevents HL' and 53% to the statement 'Laws exist to protect workers from being exposed to high noise at work' (Figure 1).

Overall 76% of the participants had a positive attitude to the importance of noise reduction at the workplace, NIHL, audiometry and wearing of hearing protection devices. Findings from specific items show that about 86% of the participants 'strongly disagreed' with the statement 'I think ear-screening program (audiometry) is not so important at my workplace', 80% with the statement 'I feel wearing hearing protection devices during work is a burden and is uncomfortable' and about 66% with the statement 'I don't work in noise level that may harm my hearing' (Figure 2). However, about 78% 'strongly disagreed' with the statement 'I feel my employer should be informed if I have HL' and about 61% with the statement 'I feel it is our shared responsibility to reduce workplace noise exposure' (Figure 2).

About 94% of the participants displayed poor practice regarding provision and use of hearing protection devices, health and safety training and audiometry (Figure 3). The majority of the participants responded 'Never' to most of the statements. For example, 82% responded 'Never' to the statement 'availability of

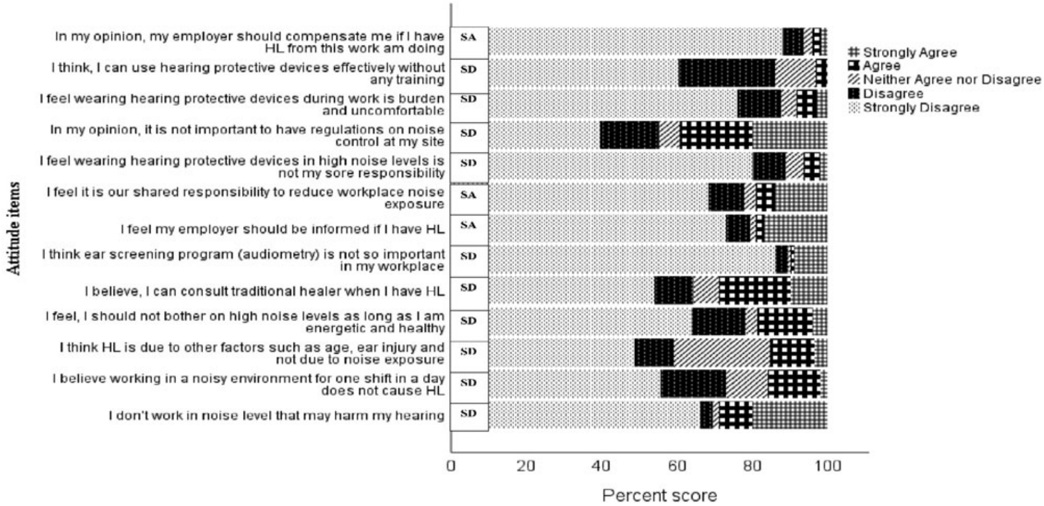

Figure 2. Attitude score (as a percentage) for noise exposure and control, noise-induced hearing loss (NIHL), audiometry and wearing of hearing protection devices for various items in 253 iron and steel workers in Tanzania. The correct answer is indicated in a box following each statement, where SD = Strongly disagree and SA = Strongly agree.

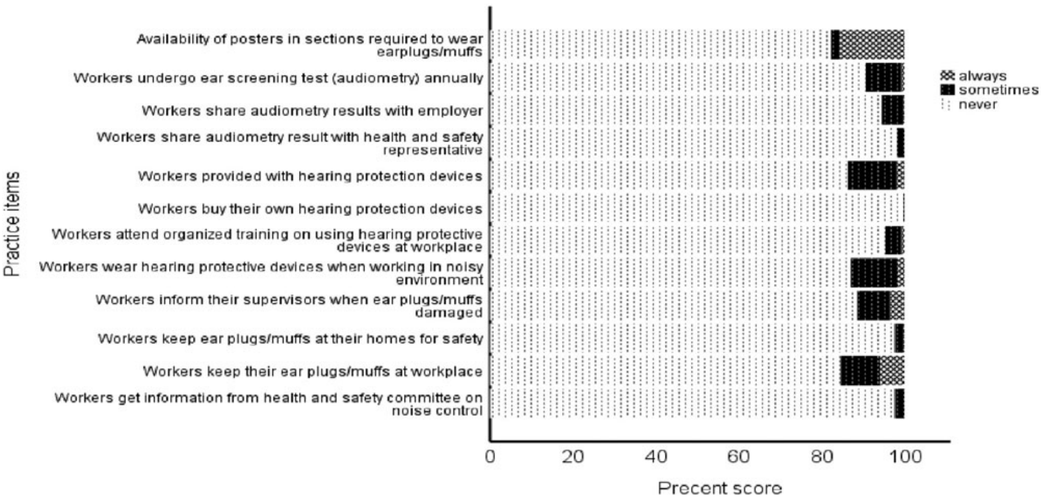

Figure 3. Percentage score for 13 items used for assessment of workers' practice in a study among 253 iron and steel workers in Tanzania.

posters in sections required to wear earplugs/muffs', 95% to the statement 'Workers attend organized trainings on using hearing protection devices at the workplace' and 91% to the statement 'Workers undergo ear-screening test (audiometry) annually'. In addition, 86% of the participants responded 'Never' to 'Workers provided with hearing protection devices at work', and a similar percentage responded likewise to 'Workers wear hearing protection devices when working in a noisy environment' (Figure 3).

Discussion

Overall few workers in the four iron and steel factories had a good knowledge of NIHL. In addition, a majority of them displayed poor practice regarding use of hearing protection devices and a considerable number of them reported non-availability of these devices at their workplaces. However, the majority were found to have a positive attitude to the importance of noise reduction at the workplace, NIHL, audiometry and wearing of hearing protection devices.

This suggests limited availability of education and training and a lack of hearing protection devices for workers.

A study of Malaysian quarry workers found a high prevalence of NIHL (57%), with a low level of knowledge (11%) among workers.[19] The present study found a fairly similar result, with the majority of our study participants displaying poor knowledge, and in these workers, the prevalence of NIHL was found to be high, i.e. 48%.[25] A study of Ghanaian mill workers also reported similar findings, with a high prevalence of NIHL (44%) and a relatively low level of knowledge (55%).[29] Thus, in these three studies there is an association between a low level of knowledge and a high prevalence of NIHL among noise exposed workers. Contrastingly, a study of Nigerian steel-mill workers found a good level of knowledge in workers (93%),[22] but a high prevalence of NIHL (57%),[30] indicating that a good level of knowledge may not be sufficient to prevent NIHL, and that there may be other contributory factors.[31]

Our study participants displayed less knowledge of specific items, e.g. whether noise exposure may cause NIHL, than workers in Malaysian sawmills (78%) and Nigerian steel-mills (93%).[20,22] The high knowledge score in those studies was presumably the result of personal experience of work in a noisy environment.[22,32] In addition, the majority of our participants were not aware that stopping work in a high noise level will not result in complete recovery if NIHL has already been acquired, compared with 54% and 22% among workers in Malaysian sawmills and quarries respectively. One explanation may be the lack of an effective education and training program regarding occupational noise hazards and related hearing loss among iron and steel workers. An integrated education and training program for workers may thus be appropriate to improve workers' knowledge of NIHL.[14,15,29]

Our findings indicate that the majority of our study participants had a positive attitude to the importance of noise reduction at the workplace, NIHL, audiometry and wearing of hearing protection devices. One explanation may be what they perceive to be the risk of working in noisy environment. Our finding is in line with two studies of Malaysian sawmill and quarry workers, whose attitude scores were 61% and 70% respectively.[19,20] The positive attitude of our study participants may be regarded as an intention to change their behavior,[33] and is likely to be a good sign for future preventive work.

The attitude of our participants regarding specific items was analogous to that ascertained in the studies of Malaysian sawmill and quarry workers.[19,20] Most workers had a positive attitude to use of hearing protection devices. For example, 80% of our participants had a positive attitude, whilst in Malaysian sawmill and quarry workers the proportional of the participants were 92% and 94% respectively. This may indicate the potential success of noise-preventive measures, including provision of hearing protection devices. In addition, 86% of our participants had a positive attitude to ear screening, comparable to that in Malaysian sawmill and quarry workers, ie 84% and 89% respectively. However, 78% had a negative attitude to sharing their ear-screening (audiometry) results with their employers – an attitude quite similar to that displayed by Malaysian quarry workers (87%).[19] This careful attitude may be due to a fear of losing their job. It may also be due to a lack of knowledge of the effect of occupational noise exposure on hearing.

Our results show that participants who have received secondary and tertiary education displayed better practice than those who have received primary education. Our findings are in line with a study of Malaysian quarry workers, where workers who had received education below secondary level displayed ignorance of the use of personal protective equipment.[19] This is probably because of the increased knowledge gained in school, which can sometimes be translated into the way people think and act. Surprisingly, in our study workers who had received primary education had a more positive attitude to the importance of noise reduction at the workplace, NIHL, audiometry and wearing of hearing protection devices. than those who had received secondary and tertiary education. These findings differ from those for Malaysian quarry workers. One of the explanations may be that formal education does not necessarily change human perception of workplace hazards such as noise. Also, the difference between our study and the Malaysian quarry study might lie in the methodology, whereby workers who had not received any formal education were compared with those who had received a formal education, whilst there were no workers who had not received a formal education in our present study.

In our study the overall practice was poor, as only 14% of the participants had been provided with and used hearing protection devices. In addition, factory D has the lowest practice score among others. This is analogous to the Malaysian sawmill and quarry studies, where 12% and 14% of workers respectively used hearing protection devices.[20] This may in part be explained by the non-availability of these devices in iron and steel factories. Although we did not find any information regarding provision of hearing protection devices for workers in the Malaysian studies, it is likely that non-provision of personal protective equipment by employers at the workplaces was the reason for a low level of utilization of the protective measures, or even non-utilization.[34] A study of Nigerian steel mill workers reported provision of hearing protection devices for only 27% of workers, indicating that non-provision of these devices for workers was a problem.[22] This provides a clue as to why only a very low proportion of workers (<10%) in these studies reported having attended training on occupational safety and health issues, including the use of hearing protection devices. This underlines the importance of provision of hearing protection devices at workplaces where workers are exposed to harmful noise. On the other hand, the non-availability of ear-screening programs for workers in our present study is analogous to the situation in the two studies of Malaysian sawmill and quarry workers, where only 6% and 2%, respectively, of workers reported having undergone ear screening, which might be interpreted as either poor coverage and/or ineffective implementation of reported in developing countries.[2,7]

The strengths of this study include a high participation rate. In addition, items within the three KAP domains displayed a high internal consistency, and we used a previously validated questionnaire. However, interview-based questionnaires may be subjected to a socially desirable reporting bias. We explained the objective of the project, and the interview was carried out in private. This reduces the fear of disclosing confidential information, hence we have no reason to suspect any motivation that might have influenced the result. Also, the research team was available in the factories during data collection, and this was probably good as regards obtaining the correct information from participants. We used a large sample size, and our participants were randomly selected from the list of workers provided by the administration, thereby minimizing the selection bias.

Our study participants were male workers in the production line in large-scale iron and steel factories exposed to a high noise level, thus our findings may be valid for other groups of workers with similar workplace characteristics.

In Tanzania the Occupational Safety and Health Act (OSHA) No. 5 of 2003 requires the employer to provide and maintain effective personal protective equipment (hearing protection devices) for the use of employees, and to conduct a thorough pre-placement as well as periodic medical examinations (including ear screening in this case). However, our findings indicate that the practical implementation of these requirements was poor. This might be the case for other low- and middle-income countries.[7,10] Thus, results from this study may be used by stakeholders at all levels, as a reflection of the status of implementation of occupational safety and health policy, legislation and noise control-related regulations in the countries facing similar challenges. This will help in the formulation and effective implementation of workplace noise-control measures including comprehensive hearing conservation programs to protect workers from developing hearing loss.

Conclusions

This study found that the majority of workers in the studied iron and steel factories had a poor knowledge of NIHL, a positive attitude to the importance of noise reduction at the workplace, NIHL, audiometry and wearing of hearing protection devices, as well as poor practice regarding provision and use of hearing protection devices, health and safety training. With a high noise level present, noise-control measures entailing the formulation and implementation of comprehensive hearing conservation program and improved provision of hearing protection devices are suggested, to avoid NIHL.

Disclosure statement

No potential conflict of interest was reported by the authors.

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