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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:

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

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):

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

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:

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

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. Inter-correlation 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).

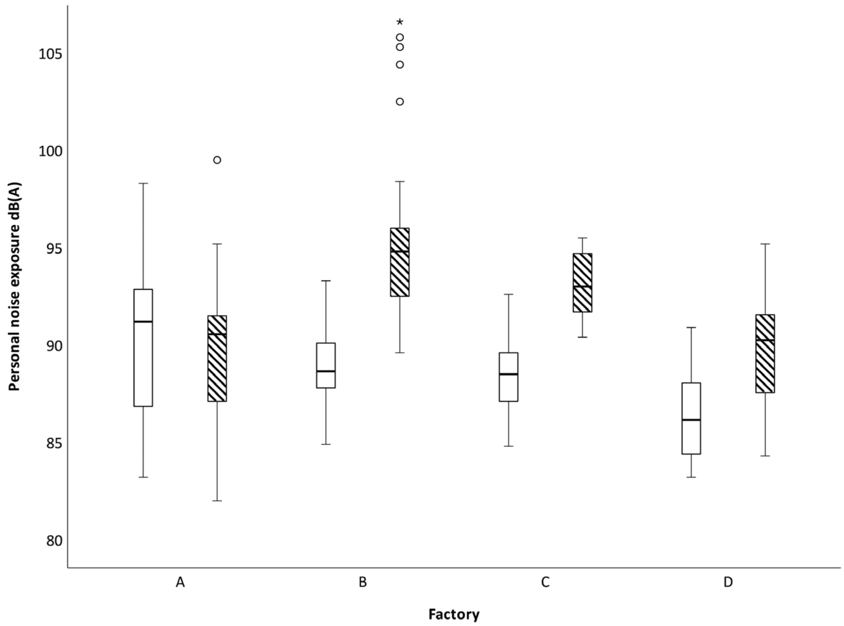

Figure 1. Personal noise exposure (n = 326) in the furnace (open boxes) and rolling mill (hatched boxes) sections for the four iron and steel factories (A, B, C, and D) in Tanzania. The boxes contain fifty percent of the noise measurements, the solid line within the boxes represents the median value 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*δ^2)		3.30 (0.61)	3.30 (0.61)	2.49 (0.35)	2.49 (0.35)
Between-worker variance (*bw*δ^2)		4.42 (1.20)	2.43 (0.87)	6.44 (1.10)	5.87 (1.0)
Between-factory variance (*bf*δ^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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