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The Effect of Noise Intensity on the Physical Fatigue of Production Operators at PT. FNF Metalindo Utama

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ABSTRACT

The manufacturing sector contributed 18.98% of Indonesia's Gross Domestic Product (GDP) in 2024, yet its production processes can generate noise levels exceeding the 85 dBA Threshold Limit Value (TLV) set by Manpower Ministerial Regulation No. 5 of 2018. This study aimed to measure noise intensity using the Equivalent Continuous Noise Level (Leq) method, assessed operators' physical fatigue using the Industrial Fatigue Research Committee (IFRC) questionnaire, and analyzed the effect of noise exceeding the exposure limit value on the physical fatigue of production operators at PT. FNF Metalindo Utama. The observational design used a quasi-experimental one-group pretest-posttest approach applied to 22 respondents drawn from a population of 28 operators, determined using the Slovin formula and simple random sampling. Physical fatigue was measured before and after the use of earplugs as the control intervention. Data were analyzed using tests for normality, linearity, and heteroscedasticity, Pearson correlation, simple linear regression, t-tests, the coefficient of determination, and a paired-difference test. Leq values across all measurement points and sessions ranged from 86.8 to 91.7 dBA, exceeding the TLV. The proportion of respondents in the high-fatigue category fell from 8 respondents (36.36%) to 1 respondent (4.55%) after earplug use. Pearson correlation showed a significant positive relationship both before ($r = 0.564$; Sig. = 0.006) and after earplug use ($r = 0.674$; Sig. = 0.001), with the coefficient of determination rising from 31.9% to 45.4%. The paired-difference test confirmed a significant reduction in fatigue ($t = 6.722$; Sig. = 0.000). Noise intensity exceeding the TLV was shown to significantly affect operators' physical fatigue, and earplugs proved effective in reducing this impact. Manufacturing companies with high noise levels are advised to consistently apply engineering controls, administrative controls, and personal protective equipment.

A. INTRODUCTION

The manufacturing sector is one of the main pillars of Indonesia's economy, accounting for 18.98% of gross domestic product in 2024 (Muda Harahap et al., 2026). Production processes that use high-productivity machinery inevitably generate mechanical noise, which constitutes the primary physical hazard in the workplace (Azrin Mohd Said et al., 2022; Rafa Zemy Amalia et al., 2025). Although Regulation No. 5 of the Minister of Labor of 2018 establishes a noise action level (NAB) of 85 dB(A) for an 8-hour workday, several studies indicate that noise levels in the manufacturing sector frequently exceed this limit for example, in the palm oil industry in West Kalimantan (Marfuah & Handayani, 2022), in the wet production area of PT Hok Tong Jambi (Salsabila et al., 2025), and in the Bintan production area (Effine Lourrinx et al., 2023;Yanti et al., 2022).

The effects of noise that exceeds safety limits have a significant impact on the health of both workers exposed to noise and those who are not exposed. Hearing disorders, such as noise-induced hearing loss, remain a global occupational health problem characterized by high prevalence (Aqsyari et al., 2023;Basu et al., 2022), which is also associated with changes in the electrocardiogram and blood pressure abnormalities (Jin et al., 2024). Non-auditory consequences manifest as increased physical fatigue, work-related stress, and decreased concentration, which carry the risk of reducing productivity and increasing the number of workplace accidents (Cudjoe et al., 2025;Ilmidin et al., 2025;Mukminin et al., 2025;Nurhayati et al., 2025). Although the relationship between noise and physical fatigue has been proven countless times, detailed studies on this non-auditory effect are still relatively limited compared to studies on hearing disorders (Pangaribuan & Widajati, 2026;Sari et al., 2023).

Based on environmental stress theory (Lazarus & Folkman, 1984), work-related fatigue arises from the interaction between environmental demands in this case, the impact of noise and the worker's adaptive capacities. When the environmental impact exceeds an individual's adaptive capacities, the body undergoes a physiological stress response, which manifests as fatigue. This level of work-related fatigue can be assessed using the Industrial Fatigue Research Committee (IFRC) questionnaire, which covers three main aspects: decreased performance, decreased motivation, and physical weakness (Maswah et al., 2024)

The use of hearing protectors is a common strategy for controlling noise exposure in the workplace. Their effectiveness depends on proper fit, consistent use, and worker training (Gong et al., 2021;Kwak & Han, 2021;Morata et al., 2024). Previous research has linked workplace noise exposure to hearing loss, cardiovascular effects, and psychological disorders (Basu et al., 2022;Aqsyari et al., 2023;Jin et al., 2024). Most studies examine these effects at a single point in time and rarely assess conditions before and after the use of hearing protection. This gap is particularly relevant at PT FNF Metalindo Utama, where cutting, shearing, bending, punching, and welding processes generate noise levels that exceed the TLV. This study measured noise intensity using Leq and assessed the physical fatigue of production operators using the IFRC questionnaire before and after the use of earplugs.

B. METHODS

This study employed a quantitative approach with a quasi-experimental design using a one-group pretest-posttest design. Measurements were conducted before and after the intervention to identify changes in physical fatigue following the implementation of the intervention (Capili & Anastasi, 2024). This design was applied to evaluate the effect of noise exposure and the intervention of personal protective equipment (earplugs) on operators' physical fatigue by comparing physical fatigue scores measured before (*pretest*) and after (*posttest*) earplug usage on a single group of production operators without a separate control group (Kwak & Han, 2021).

The study population comprised all operators working in the production area of PT FNF Metalindo Utama. The study sample consisted of 22 production operators assigned to five production stages: cutting (P1), blanking (P2), bending (P3), piercing (P4), and welding (P5). Respondents were required to work full-time in the production area throughout the measurement period and to be willing to participate as study respondents. The independent variable in this study was noise intensity (X), while the dependent variable was physical fatigue (Y). The operational definitions of both variables are presented in Table 1.

Table 1 Operational Definitions of Research Variables

Variable	Operational Definition	Measurement Tool	Scale
Noise Intensity (X)	The equivalent sound pressure level received by the operator while working, expressed as an Leq value in dB(A)	5 in 1 Environment Meter	Ratio
Physical Fatigue (Y)	The decline in an operator's physical work capacity, as measured by the total IFRC questionnaire score	IFRC Questionnaire	Interval

Source: Processed from the research instrument, 2026.

Noise intensity was measured using a 5-in-1 Environment Meter that was calibrated before use, at five production process points (P1-P5) and five work-time intervals (L1-L5) representing one full daily operating cycle, with readings taken every 5 seconds over 10 minutes at each point. The resulting noise values were then processed using the Equivalent Continuous Noise Level (Leq) method to obtain an equivalent noise level representing noise exposure during the measurement period. In addition, the day night noise level (Lsm), the maximum permissible exposure time based on the NIOSH (1998) standard, and the Daily Noise Dose (DND) were calculated to provide a more comprehensive assessment of noise hazard risk.

Physical fatigue was measured using the Industrial Fatigue Research Committee (IFRC) questionnaire, an instrument widely used to measure work fatigue because of its good validity and reliability. The questionnaire consists of 30 items covering three dimensions weakening of activity, weakening of motivation, and physical weakening with each item rated on a 1-4 scale, giving a total score ranging from 30 to 120. The total score is then classified into four work-fatigue categories, as presented in Table 2.

Table 2 Work Fatigue Category Based on the IFRC Questionnaire

No.	Category	Score Range	Notes
1	Low	30–52	No significant fatigue
2	Moderate	53–75	Noticeable fatigue; requires attention
3	High	76–98	Severe fatigue; requires immediate attention
4	Very High	99–120	Extreme fatigue; hazardous to health

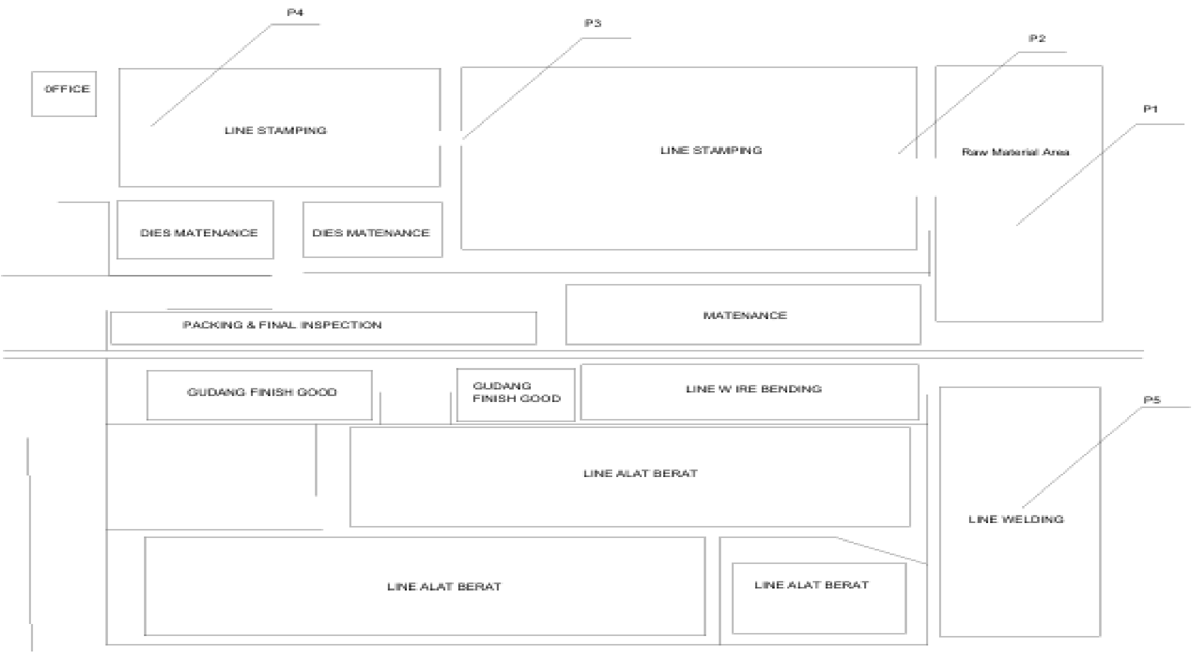
Source: Industrial Fatigue Research Committee (IFRC) questionnaire instrument

Data were analyzed using SPSS software through eight testing stages: the Shapiro-Wilk normality test, linearity test, Glejser heteroscedasticity test, Pearson correlation test, simple linear regression analysis, partial hypothesis testing (t-test), coefficient of determination (R^2), and a paired-sample t-test to compare fatigue levels before and after the intervention (Sugiyono, 2019).

C. RESULT AND DISCUSSION

1. Noise Intensity Level

Equivalent Continuous Noise Level (Leq) measurements were taken at five points representing the production process stages: P1 (cutting), P2 (blanking), P3 (bending), P4 (piercing), and P5 (welding), as shown in Figure 1.



Source: Processed primary data, 2026.

Figure 1 Noise Intensity Measurement Points in the Production Area

Measurements were taken at five time intervals representing production operating conditions over one working day: L1 (08:00-10:00), L2 (10:00-12:00), L3 (13:00-15:00), L4 (16:00-21:00), and L5 (22:00-01:00), with readings taken every 5 seconds over 10 minutes at each point. During intervals L4 and L5, measurements were taken only at points P2, P3, and P4, since production activity at points P1 and P5 had already ended, in line with the company's actual operating conditions. The Leq value was calculated using the following equation:

$$Leq = 10 \log_{10} [(1/n) \times \Sigma 10^{Li/10}] \quad (1)$$

where Li is the noise value at the i-th measurement in dB(A) and n is the number of measurement data points. As an illustration, the Leq calculation for point P1 in interval L1 (at 09:20, representing 08:00-10:00) with n = 24 data points yields:

Table 3 Noise Intensity Measurement for L1, Taken at 09:20, Representing 08:00–10:00

Location	**P1**		**P2**		**P3**		**P4**		**P5**	
Time	Minute 1	Minute 2	Minute 3	Minute 4	Minute 5	Minute 6	Minute 7	Minute 8	Minute 9	Minute 10
Second 5	92.1	97.7	90.6	87.1	88.1	85.6	86.0	90.3	83.2	87.3
Second 10	96.3	90.8	86.5	90.0	93.5	87.0	85.3	87.4	86.7	84.6
Second 15	89.4	95.7	87.3	89.2	91.2	90.3	87.9	88.5	86.2	86.2
Second 20	86.2	93.3	84.1	91.3	90.3	89.2	90.7	91.8	85.9	86.9
Second 25	90.1	91.1	89.7	92.5	89.8	89.3	89.2	89.5	86.3	85.4
Second 30	86.0	88.8	91.5	90.5	91.4	91.0	89.6	89.2	84.8	87.2
Second 35	84.9	92.8	92.8	89.4	88.4	91.5	91.4	93.0	87.5	87.8
Second 40	86.5	85.6	93.0	92.4	89.7	92.1	93.9	91.7	88.3	88.1
Second 45	87.3	95.4	94.4	93.1	91.0	86.8	87.2	90.5	87.1	86.5
Second 50	85.5	91.6	92.0	93.7	93.3	91.2	85.1	84.1	85.2	89.2

Second 55	82.1	90.9	88.7	91.0	85.6	94.3	88.2	85.0	86.6	85.1
Second 60	84.0	86.8	87.3	90.8	84.3	86.5	86.5	84.9	89.7	85.7

Source: Processed primary data, 2026.

$$Leq = 10 \log_{10} (34.538.854.802 / 24) = 10 \times 9{,}16 = 91{,}5 \text{ dB(A)}$$

The same calculation procedure was applied to all other measurement points and intervals, with the summary of results presented in Table 4.

Table 4 Summary of Leq Values at Each Measurement Point and Interval, in dB(A)

Measurement Points	L1	L2	L3	L4	L5
P1 (Cutting)	91,5	91,6	91,7	–	–
P2 (Blanking)	91,0	91,0	90,9	87,6	88,8
P3 (Bending)	90,3	89,7	90,9	88,3	89,2
P4 (Piercing)	89,4	90,5	88,3	87,9	89,5
P5 (Welding)	86,8	86,9	87,1	–	–
Overall Leq	**90,1**	**90,2**	**90,1**	**88,0**	**89,2**

Note: the symbol "–" indicates that the point was not measured because production activity had already ended.

Source: Processed primary data, 2026.

The highest Leq value across all time intervals was recorded at point P1 (Cutting), at 91.7 dB(A) during interval L3 (13:00-15:00), while the lowest value was found at point P5 (Welding), at 86.8 dB(A) during interval L1 (08:00-10:00). Overall, the combined Leq value across all time intervals ranged from 88.0 to 90.2 dB(A), indicating relatively small noise fluctuation during the production process. All measurement results exceeded the 85 dB(A) Threshold Limit Value (TLV) set by Manpower Ministerial Regulation No. 5 of 2018. This indicates that production operators experience continuously high noise exposure throughout working hours, which could increase the risk of physical fatigue and health problems if not offset by adequate noise-control measures.

Day-Night Noise Level and Exposure Risk

To more comprehensively assess noise exposure risk, the day-night noise level (Lsm) was calculated in accordance with Keputusan Menteri Negara Lingkungan Hidup No. 48 Tahun 1996 Tentang Baku Tingkat Kebisingan, 1996, the maximum permissible exposure time was determined based on the NIOSH (1998) standard, and the Daily Noise Dose (DND) was calculated.

Calculation of the Day-Night Noise Level (Lsm)

1) Daytime Noise Level (L_S)

$$L_S = 10 \log_{10}\left(\frac{1}{T_S}\sum_{i=1}^{n}(T_i \times 10^{0.1L_i})\right) \quad (2)$$

$$L_S = 10 \log_{10}\left(\frac{1}{11}\sum_{i=1}^{4}(T_1 \times 10^{0.1x\,90.1} + T_2 \times 10^{0.1x\,90.2} + T_3 \times 10^{0.1x\,90.1} + T_4 \times 10^{0.1x\,88.0})\right)$$

$$L_s = 10 \times \log_{10}\left(\frac{1}{11} \times 9.34221578\right)$$

$$L_S = 10 \log_{10}\left(\frac{9.34221578}{11}\right)$$

$$L_s = 10 \times 8.929057209 = 89.2 \text{ dB(A)}$$

2) Calculation of the Nighttime Noise Level (L_M)

$$L_M = 10 \log_{10}\left(\frac{1}{T_M}(T_{L5} \times 10^{0.1L_5})\right) \quad (3)$$

$$L_M = 10 \log_{10}\left(\frac{1}{3}(3 \times 10^{0.1\times 89{,}2})\right)$$

$$L_M = 10 \log_{10}\left(\frac{1}{3}2.49529131\right)$$

$$L_M = 10 \times 8.919999998 = 89.1 \text{ dB(A)}$$

3) Day-Night Noise Level (L_{SM})

$$L_{SM} = 10 \log_{10}\left(\frac{1}{24}\left(16 \times 10^{0.1L_S} + 8 \times 10^{0.1(L_M+5)}\right)\right) \quad (4)$$

$$L_{SM} = 10 \log_{10}\left(\frac{1}{24}\left(16 \times 10^{0.1\text{x}\,89.2} + 8 \times 10^{0.1(89.1+5)}\right)\right)$$

$$L_{SM} = 10 \log_{10}\left(\frac{1}{24} 3.43503642\right)$$

$$L_{SM} = 10 \log_{10}\left(\frac{1}{24} 3.43503642\right)$$

$$L_{SM} = 10 \times 9.155720104 = 91.5 \text{ dB(A)}$$

Maximum Noise Exposure Time (NIOSH 1998)

$$T = \frac{8}{2^{\frac{L-85}{3}}} \quad (5)$$

$$T = \frac{8}{2^{\frac{91.5-85}{3}}}$$

$$T = \frac{8}{2^{2.166666667}}$$

$$T = \frac{8}{4.489848193}$$

$$T = 1.781797436$$

Daily Noise Dose (DND)

$$DND(\%) = \left(\frac{C}{T_{izin}}\right) \times 100\% \quad (6)$$

$$DND(\%) = \left(\frac{24}{1.781797436}\right) \times 100\%$$

$$DND(\%) = 1346\%$$

Table 5 Day-Night Noise Level, Maximum Exposure Time, and Daily Noise Dose

Parameter	Result	Notes
Daytime Noise Level (Ls)	89.2 dB(A)	Combined Leq for intervals L1-L4
Nighttime Noise Level (Lm)	89.1 dB(A)	Leq for interval L5 (nighttime)
Day-Night Noise Level (Lsm)	91.5 dB(A)	Exceeds the 70 dB(A) industrial area noise quality standard
Maximum Exposure Time (NIOSH 1998)	1.78 hours/day	Far below the normal work duration (8 hours/day)
Daily Noise Dose (DND)	1,346%	Exceeds the safe dose threshold (100%)

Source: Processed primary data, 2026.

The Lsm value of 91.5 dB(A) exceeds the 70 dB(A) industrial area noise quality standard by 21.5 dB(A). Based on the NIOSH (1998) standard, the maximum permissible exposure time at this noise level is only 1.78 hours (about 1 hour 47 minutes) per day, far below the normal 8-hour workday. The DND value of 1,346% (far above 100%) confirms that the production area carries a very high noise hazard risk and could accelerate the onset of Noise-Induced Hearing Loss (NIHL) if not accompanied by adequate controls.

2. Operator Physical Fatigue

In addition to the Leq data, direct measurements were also taken of the average noise intensity received by each operator at their workstation using a 5 in 1 Environment Meter, serving as the independent variable (X) in the statistical analysis. Each operator's physical fatigue level was measured using the IFRC questionnaire as the dependent variable (Y).

Table 6 Summary of Noise Intensity and Work Fatigue (Before Earplug Use)

No.	dB(A)	Score	Category	No.	dB(A)	Score	Category
1	93.7	82	High	12	87.8	60	Moderate
2	88.5	75	Moderate	13	92.2	85	High
3	94.2	83	High	14	94.3	84	High
4	90.2	65	Moderate	15	88.6	82	High
5	92.0	75	Moderate	16	87.5	71	Moderate
6	86.2	50	Low	17	88.6	54	Moderate
7	86.8	62	Moderate	18	87.6	74	Moderate
8	88.8	74	Low	19	91.2	49	Moderate
9	90.8	82	High	20	94.5	85	High
10	90.0	60	Low	21	88.6	79	High
11	89.6	62	Moderate	22	89.8	64	Moderate

Source: Processed primary data, 2026.

Table 7 Summary of Noise Intensity and Work Fatigue (After Earplug Use)

No.	dB(A)	Score	Category	No.	dB(A)	Score	Category
1	93.7	56	Moderate	12	87.8	50	Moderate
2	88.5	48	Low	13	92.2	57	Low
3	94.2	75	Moderate	14	94.3	55	Moderate
4	90.2	62	Moderate	15	88.6	48	Moderate
5	92	56	Moderate	16	87.5	42	Low
6	86.2	35	Low	17	88.6	48	Low
7	86.8	65	Moderate	18	87.6	43	Low
8	88.8	52	Low	19	91.2	55	Low
9	90.8	59	Moderate	20	94.5	76	Moderate
10	90	52	Low	21	88.6	58	High
11	89.6	49	Moderate	22	89.8	55	Moderate

Source: Processed primary data, 2026.

The average noise intensity received by operators ranged from 86.20 to 93.7 dB(A), with a mean value of 90.07 dB(A), indicating that all operators were exposed to noise above the 85 dB(A) TLV. The distribution of work-fatigue categories is presented in the table 8.

Table 8 Comparison of Work-Fatigue Dimension Scores and Percentages Based on the IFRC Method Before and After Earplug Use

IFRC Dimension	Score Before	Score After	Score Decrease	Decrease (%)
Weakening of Activity	21.86	17.55	4.31	19.72
Weakening of Motivation	19.59	16.18	3.41	17.41
Physical Weakening	29.32	20.64	8.68	29.60
Total	**70.77**	**54.36**	**16.41**	**23.19**

Sumber: Data primer diolah, 2026.

Based on the comparison of IFRC scores before and after earplug use, all dimensions showed a decrease in fatigue score. The total IFRC score decreased from 70.77 to 54.36, a reduction of 16.41 points, indicating a decline in fatigue levels after workers began using earplugs. The largest decrease occurred in the physical weakening dimension, from 29.32 to 20.64 (a decrease of 8.68 points), indicating that earplug use had the greatest effect in reducing physical complaints related to noise exposure. The weakening of activity dimension also decreased, from 21.86 to 17.55, while weakening of motivation decreased from 19.59 to 16.18. Although the percentage contribution of each dimension to the total score changed slightly because the overall total score decreased, the distribution pattern still shows that physical weakening was the most dominant dimension both before and after earplug use. These results indicate that earplug use is effective in reducing work-fatigue levels, particularly in the physical aspect, and could therefore improve workers' comfort and ability to carry out work activities in high-noise-intensity environments.

Effect of Noise Intensity on Work Fatigue

The classical assumption tests showed that the data were normally distributed (Shapiro-Wilk Sig. > 0.05 for all variables), the relationships between variables were linear, and the regression model was free of heteroscedasticity under both conditions (Glejser test Sig. = 0.156 before and Sig. = 0.678 after earplug use). Meeting these assumptions ensures that the correlation and regression test results can be validly interpreted.

The Pearson correlation test showed a significant positive relationship between noise intensity and work fatigue, both before (r = 0.564; Sig. = 0.006) and after earplug use (r = 0.674; Sig. = 0.001). Simple linear regression analysis produced the equation $Y = -166.639 + 2.636X$ before earplug use and $Y = -178.834 + 2.589X$ after earplug use, with a significant t-test result under both conditions (Sig. = 0.006 and Sig. = 0.001). The coefficient of determination rose from 31.9% before to 45.4% after earplug use, indicating that noise intensity became a more dominant predictor of fatigue once some of the variation from other confounding factors was reduced by the earplugs. The paired-difference test confirmed a significant reduction in fatigue after earplug use (t = 6.722; Sig. = 0.000). These results are summarized in Table 9.

Table 9 Summary of Classical Assumption, Correlation, Regression, and Paired-Difference Test Results

Statistical Test	Before Earplug Use	After Earplug Use
Heteroscedasticity (Glejser Sig.)	0.156	0.678
Pearson correlation (r)	0.564	0.674
Correlation significance (Sig.)	0.006	0.001
Simple linear regression equation	$Y = -166.639 + 2.636X$	$Y = -178.834 + 2.589X$
Regression significance (Sig.)	0.006	0.001
Coefficient of determination (R^2)	31.9%	45.4%

Source: Processed primary data by SPSS, 2026.

This positive correlation is consistent with previous findings linking workplace noise to work-related stress and physiological health indicators (Azrin Mohd Said et al., 2022;Jin et al., 2024). Previous studies examined different outcome measures and did not employ a pre-post intervention design. This comparison primarily focuses on the direction of the relationship between the two variables. The increase in the R^2 value from 31.9% to 45.4% should be interpreted with caution. Earplugs can reduce the amount of noise to which the ears are exposed, but they do not alter the Leq values measured in the workplace. The stronger association observed after the intervention may reflect reduced noise-related stress, differences in workload, differences in rest periods, increased consistency in questionnaire responses, or a placebo effect. These factors were not directly measured. Future controlled studies should investigate these factors.

D. CONCLUSION AND SUGGESTIONS

Noise levels in the production area of PT. FNF Metalindo Utama were found to consistently exceed the Threshold Limit Value (TLV) of 85 dB(A), which directly contributes to high workloads and physical fatigue among operators. However, the use of earplugs demonstrated statistically significant effectiveness in reducing the total work fatigue score (based on the IFRC instrument) from 70.77 to 54.36. The greatest reduction occurred in the dimension of physical exhaustion, resulting in a drastic decrease in the number of operators in the high-fatigue category, from 8 to just 1 person. Statistical analysis confirms that the use of hearing protection plays a crucial role in mitigating the adverse effects of noise, although other external factors also influence workers' fatigue levels.

The company is advised to implement a comprehensive hazard control strategy. From an engineering perspective, it is recommended to install acoustic barriers at workstations with the highest noise levels. Administratively, companies need to implement work rotation given that the safe exposure limit according to NIOSH standards is only about 1.78 hours per day as well as enforce the consistent use of earplugs, supported by training and periodic audiometric testing. Meanwhile, future research is advised to include additional variables that influence work-related fatigue and to use a longitudinal approach to observe the long-term accumulation of hearing loss risk.

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