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Original article

Effect of ergonomic engineering innovation on musculoskeletal symptoms during mining heavy load handling in Chile

Efecto de innovación ergonómica en síntomas musculoesqueléticos durante manejo de cargas mineras en Chile

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ABSTRACT

Introduction: Ergonomics is essential for preventing work-related musculoskeletal disorders, particularly in physically demanding sectors such as mining. In Chile, tasks involving overexertion and awkward postures significantly increase ergonomic risk. Engineering controls have shown effectiveness in reducing physical workload and improving occupational health.

Objective. To evaluate the effectiveness of an engineering control applied to the replacement of a variable frequency drive (VFD) in reducing ergonomic risks and musculoskeletal symptoms among mining workers.

Methods: A mixed, cross-sectional experimental study was conducted with 15 mining workers. Ergonomic risk and musculoskeletal symptoms were assessed using the Technical Guide for Manual Load Handling, the

Standardized Nordic Questionnaire, and the Borg CR-10 Scale. The intervention consisted of implementing a mechanical arm with a hoist to assist VFD handling, comparing pre- and post-intervention conditions.

Results: Before the intervention, handling the VFD (30–45 kg) required asymmetric postures and high physical effort, resulting in musculoskeletal pain, mainly in the lower back (66.7%) and shoulders (26.7%), with perceived exertion rated as very strong (7). After the intervention, pain decreased significantly (lower back 6.6%, shoulders 0%; $p<0.05$), and perceived exertion was reduced to very weak.

Conclusion: The engineering control effectively reduced physical load, exertion, and musculoskeletal symptoms in mining workers.

Keywords: occupational health; musculoskeletal disorder; ergonomic workstation; occupational risks

RESUMEN

Introducción: La ergonomía es esencial para prevenir trastornos musculoesqueléticos relacionados con el trabajo, especialmente en sectores físicamente exigentes como la minería. En Chile, las tareas que implican sobreesfuerzo y posturas incómodas aumentan significativamente el riesgo ergonómico. Los controles de ingeniería han demostrado ser efectivos para reducir la carga física y mejorar la salud ocupacional.

Objetivo. Evaluar la efectividad de un control de ingeniería aplicado al reemplazo de un variador de frecuencia en la reducción de riesgos ergonómicos y síntomas musculoesqueléticos entre los trabajadores de la minería.

Métodos: Se realizó un estudio experimental mixto y transversal con 15 trabajadores mineros. Se evaluaron el riesgo ergonómico y los síntomas musculoesqueléticos usando la Guía Técnica de Manipulación Manual de Cargas, el Cuestionario Nórdico Estandarizado y la Escala Borg CR-10. La intervención consistió en implementar un brazo mecánico con polipasto para asistir en la manipulación del VFD, comparando las condiciones antes y después de la intervención.

Resultados: Antes de la intervención, manipular el VFD (30–45 kg) requería posturas asimétricas y un esfuerzo físico elevado, lo que resultaba en dolor musculoesquelético, principalmente en la zona lumbar (66,7%) y los hombros (26,7%), con una percepción de esfuerzo calificada como muy fuerte (7). Después de la intervención, el dolor disminuyó significativamente (zona lumbar 6,6%, hombros 0%; $p<0,05$), y la percepción de esfuerzo se redujo a muy débil.

Conclusión: El control de ingeniería redujo de manera efectiva la carga física, el esfuerzo y los síntomas musculoesqueléticos en los trabajadores de la minería.

Palabras clave: salud ocupacional; trastorno musculoesquelético; estación de trabajo ergonómica; riesgos laborales

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Introduction

The influence of ergonomics on the evaluation, intervention, and adjustment of workstations has been significant in promoting health, preventing occupational risks, and reducing work-related musculoskeletal disorders (WRMSDs), which are among the leading causes of occupational morbidity.(1) In this regard, studies on occupational risk factors related to the likelihood of developing a WRMSD have emphasized their association with exposure to highly repetitive tasks, the use of awkward postures, and overexertion during manual material handling.(2,3)

Although efforts in occupational health prevention have been described, the International Labour Organization (ILO) indicates that WRMSDs remain a persistent problem and encourages focusing efforts through occupational safety and health program management to reduce their incidence.(4,5)

Specifically in Chile, the prevalence of WRMSDs and musculoskeletal discomfort occurs across various productive sectors, with the highest rates observed among healthcare and clinical personnel (50–65%), construction workers (45%), rural agricultural laborers, and workers in the mining sector. In men, the lumbar spine is particularly affected,(6,7,8) due to manual material handling that exceeds the effort limits established by Law No. 20,949 (25 kg for men and 20 kg for women) (Ministry of Labor and Social Welfare; 2016). These tasks are performed in awkward postures and require repeated exertion due to the nature of the worker's activity. This context underscores the need to review, evaluate, and rethink workstation design and how tasks are carried out.(9)

In mining, various ergonomic risk factors can be observed, such as the use of non-neutral postures, long shifts with rotating schedules, high physical demands, and the presence of extreme environmental conditions such as heat, cold, and wind.(10,11) Workers often perform their tasks despite discomfort, musculoskeletal pain, and injury risks.(12)

Sustained physical overload has been evidenced in comparative studies of mining populations, showing higher prevalence of musculoskeletal pain among workers performing manual material handling tasks compared to other tasks.[13] These workers also report high levels of perceived physical exertion on standardized scales.[14]

Although strategies such as active breaks and task rotation have been implemented, their effect has been limited and offers few advantages in reducing the physiological overload experienced by workers during their tasks.[15,16]

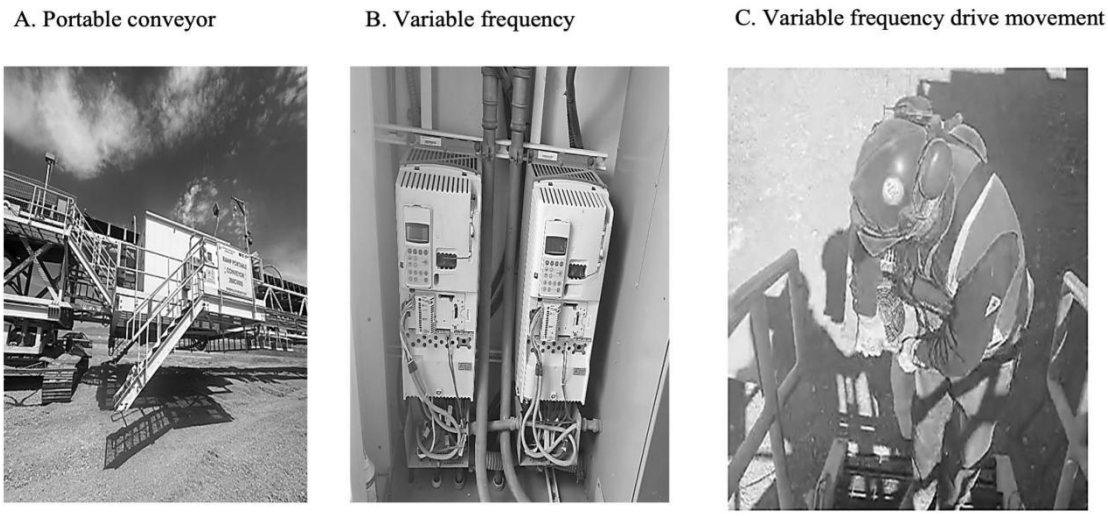
Following this line, reviews in applied and occupational ergonomics suggest that the most effective interventions are those involving engineering controls, technical solutions, or workstation redesigns that categorically reduce exposure to physical and biomechanical risk factors,[17] Indeed, interventions based on automation and mechanization principles considerably decrease workers' physical demands.[18]

Although practical application of such innovations is limited in mining, this indicates a potential area for research development, which may positively impact occupational health. Therefore, considering the above, this study focused on evaluating the effects of a pilot engineering ergonomics intervention on the musculoskeletal symptoms of workers in a task originally based on manual material handling.

To evaluate the effectiveness of the engineering control measure implemented during the variable frequency drive replacement task in reducing ergonomic risks and musculoskeletal symptoms among workers in a mining operation.

Methods

This research employed an experimental pre-post intervention design with a descriptive, cross-sectional, longitudinal, and quantitative approach. Fifteen male workers participated. Initially, an observation was conducted during the task execution in the portable conveyor area, where the electrical cabinets are in the stacking sector (figure 1).



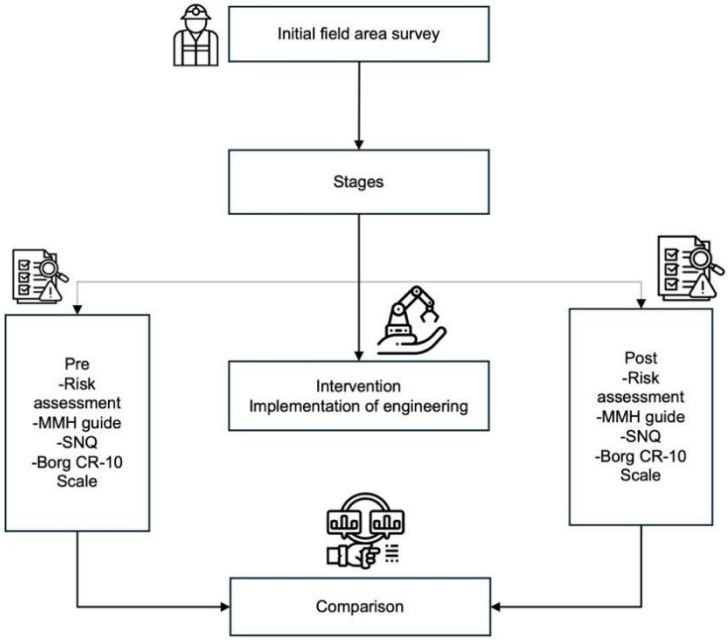
Source: Own´s elaboration.

Note: **A.** Portable conveyor sector, **B.** Variable frequency drive, **C.** Transit/movement zone.

Fig. 1. Field area where the variable frequency drive replacement is performed.

The study was structured into three stages. In the first stage, the principal investigator conducted a technical visit to observe the task and determine the number of workers performing it. Based on this information, the instruments for subsequent evaluation were selected. During a second session (the following week) and during the workers' shift, the principal investigator assessed ergonomic risks for those performing the variable frequency drive replacement task using the Manual Material Handling (MMH) Technical Guide, an instrument that examines risk factors for musculoskeletal disorders and suggests task redesign, training, or mechanical aids. Additionally, the Standardized Nordic Questionnaire (SNQ) was applied to detect musculoskeletal symptoms, particularly pain, through topographical mapping of painful body regions and recording symptoms over the past seven days and 12 months. Perceived exertion was evaluated using the Borg CR-10 Scale, where workers rate task intensity from 0 (no exertion) to 10 (maximum exertion). All evaluations were conducted on-site by the principal investigator.

The second stage involved ergonomic intervention, consisting of designing and implementing an engineering control measure, followed by a third stage of risk re-evaluation, allowing pre- and post-intervention comparisons (figure 2).



Source: Own´s elaboration.

Fig. 2. Methodological Design.

Ethical Considerations

The study was approved by the institutional ethics committee (CEC-UVM 15-24). All participants provided written informed consent.

Statistical Analysis

Descriptive and comparative statistics were used. Frequencies and percentages were calculated for categorical variables, and measures of central tendency for continuous variables. The McNemar test was applied for paired categorical variables (presence or absence of musculoskeletal pain), and paired t-tests for continuous variables (perceived exertion). Significance was set at $p<0.05$.

Results

Pre-Intervention

The MMH Technical Guide[19] and initial verification tables classified the task as high-risk, due to the load weight (variable frequency drives ranging from 30 to 45 kg depending on model and brand), exceeding legal limits established by Law No. 20,949 (25 kg for men, 20 kg for women) for individual handling. The distance between the transport vehicle and the installation site was 4–5 meters and did not constitute a major risk. The

main challenge involved lowering the equipment from the vehicle, transporting it, and ascending stairs to the installation area, requiring asymmetrical spinal postures with combined flexion and rotation, without foot movement.

Intervention

Based on these findings, an engineering control measure was implemented: a mechanical arm with hoist to lift, lower, and transport the load with multi-directional mobility. Workers only guide the load via a tension rope, significantly reducing physical effort while maintaining ergonomic comfort (figure 3).

Source: Own´s elaboration.
Note: Manual handling of the variable frequency drive involves gripping, transporting, and lowering the equipment.
Fig. 3. Transport of the variable frequency drive using an engineering control measure.

Post-Intervention

Reassessment using the same instruments (MMH guide, SNQ, Borg scale) revealed significant reductions in both musculoskeletal pain prevalence and perceived exertion. Lumbar pain decreased from 66.7 to 6.6%, and shoulder pain from 26.7% (four workers) to 0%. Overall, 80% of workers reported pain in the past 7 days pre-intervention, while none reported pain post-intervention. All differences were statistically significant ($p<0.05$, McNemar test), (table 1). Perceived exertion dropped from a rating of 7 (“very hard”) pre-intervention to 1 (“very light”) post-intervention ($p<0.05$, paired t-test), (table 2).

Table 1. Prevalence and total duration of musculoskeletal pain in workers by body region based on the Standardized Nordic Questionnaire (SNQ)

Body area with pain	Pre		Post	
	n	%	n	%
Lumbar spine	10	66.7	1	6.6*

Shoulder	4	26.7	0	0*
Cervical spine	1	6.6	0	0*
Pain duration (last 7 days)				
1-7	12	80.0	0	0*
8-30	2	13.3	1	6.6*
>30	1	6.6	0	0*

Significance McNemar *p<0.05

Source: Own´s elaboration.

Table 2. Workers perceived exertion according to the Borg CR-10 Scale

Perceived exertion	Pre	Post
Value	7	1*
Qualitative rating	"very hard"	"very light"
% of maximum voluntary contraction	70%	10%

Significance t-test *p<0.05.

Source: Own´s elaboration.

Discussion

The ergonomic innovation led to a significant reduction in lumbar, cervical, and shoulder pain, likely due to decreased mechanical load, reduced forced postures, and diminished spinal compression. Similar results have been reported with mechanical aids and exoskeletons in tasks requiring awkward postures and manual load handling.[20,21] Hwang (2020) also demonstrated that pneumatic-assisted devices reduce injury risk in caregivers for the lumbar spine and upper extremities.[22]

Comparing engineering controls with traditional administrative strategies (task rotation, training, active breaks), the mechanical arm with hoist redefined the task's technical and biomechanical demands, substituting physical, muscular, and postural effort with a supervisory role of guiding the load, consistent with Bey-Temsamani (2022), who designed an intelligent overhead crane for large load handling.[23] These findings align with prior mining interventions showing that mechanical or teleoperated assistance relocates workers away from the physical core, reducing ergonomic exposure.[15]

The study highlights the importance of ergonomics in occupational risk management, particularly under high load and extreme environmental conditions. The intervention aligns with occupational ergonomics principles advocating primary engineering controls to prevent WRMSDs and support sustainable productivity.[24] The

prototype's low cost and adaptability enable replication across mining, industrial, and healthcare settings with similar manual handling tasks.[25]

Sornumen et al. (2022) noted positive outcomes of ergonomics on work retention, health perception, and reduced absenteeism due to lumbar pain.[26] reinforcing the value of such strategies from a biopsychosocial perspective.

This study contributes evidence on the preventive effects of mechanization against WRMSDs, showing that simple engineering solutions can mitigate biomechanical exposure and reduce physical load. Considering demographic changes in the workforce, similar ergonomically innovative tools may protect worker health, safety, and aging.

Finally, the mixed-method approach proved valuable for guiding future interventions in real-world settings. Using both ergonomic risk assessment tools and instruments measuring exertion and musculoskeletal pain (Borg CR-10, SNQ) yielded statistically supported findings despite a small sample size (n=15).

Limitations and future directions

Limitations include a small sample (n=15) and lack of longitudinal follow-up due to project-based contracts. Future studies could integrate additional indicators such as fatigue, performance, and productivity, with larger samples and medium-term evaluations to assess sustainability of effects.

Conclusion

Finally, this study allow us to reflect that the ergonomic innovation, through the mechanical arm, was highly effective in reducing musculoskeletal risk in occupational tasks involving heavy load handling. Specifically, the intervention significantly reduced physical load, perceived exertion, and musculoskeletal symptoms among mining workers.

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Conflict of interest

The authors declare that they don't have conflict of interest.

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