Sciences Methods and Technologies International Journal (SciMeTech)

ISSN: 3085-5284, journal homepage: www.scimetech.com

Cognitive and Physical Workload in Lean Work Systems and Work-limiting Musculoskeletal Symptoms: Evidence from Moroccan Industries

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How to cite:

Yasmine Benhammane, Naoufal Sefiani, "Cognitive and Physical Workload in Lean Work Systems and Work-limiting Musculoskeletal Symptoms: Evidence from Moroccan Industries", Sciences Methods and Technologies International Journal (SciMeTech), Vol 2, Issue 1, p 27-33

Keywords:
Lean production
Cognitive workload
Musculoskeletal disorders
Physical effort
Occupational health

Abstract

Lean production systems are often promoted for improving efficiency, yet their implications for worker health remain debated, particularly regarding musculoskeletal disorders (MSDs). This study examines how cognitive workload and perceived physical effort are associated with work-limiting musculoskeletal symptoms in Lean production environments in Morocco. A quantitative cross-sectional study was conducted among 150 workers operating in Lean contexts. Cognitive workload was assessed using a composite measure derived from the NASA Task Load Index, while physical effort was measured using the Borg CR-10 scale. Musculoskeletal outcomes were assessed using items from the Nordic Musculoskeletal Questionnaire, with the primary outcome defined as the presence of at least one work-limiting musculoskeletal symptom. Logistic regression analysis was used to estimate the likelihood of work-limiting MSDs as a function of cognitive workload and physical effort, controlling for professional seniority. Exploratory analyses examined differences in workload exposure across seniority groups.

Both cognitive workload and perceived physical effort were significantly associated with an increased likelihood of experiencing work-limiting musculoskeletal symptoms. These associations remained significant after controlling for seniority, which did not emerge as a significant predictor. Exploratory analyses indicated that levels of cognitive workload and physical effort varied across seniority categories, suggesting differentiated exposure patterns within Lean work systems.

The findings indicate that work-limiting musculoskeletal symptoms in Lean production environments are shaped by the combined effects of cognitive and physical workload demands rather than by experience alone. By integrating cognitive workload into the analysis of musculoskeletal outcomes, this study highlights the need to move beyond purely biomechanical perspectives and to consider system-level work design factors. Sustainable prevention of MSDs in Lean contexts requires explicit attention to both cognitive and physical demands embedded in the organization of work.

I. Introduction

Lean manufacturing is widely adopted as an operations philosophy designed to improve quality, delivery, and productivity through waste elimination, standardized work, and continuous improvement practices (Womack et al., 1990; Liker, 2004). Its diffusion has extended far beyond its origins in automotive production, reaching a broad range of industrial sectors and organizational forms, including export-oriented production networks where performance expectations are strongly driven by global customers and tight delivery commitments.

At the same time, a substantial body of evidence indicates that Lean and closely related high-performance work systems can reshape work organization in ways that affect employee well-being. Reported mechanisms include work intensification, elevated time pressure, tighter control of work pace, reduced buffers, and increased reliance on standardized execution, which may jointly increase both cognitive and physical workload (Landsbergis et al., 1999; Hasle et al., 2012; Huo et al., 2022). These concerns are relevant not only from a worker health perspective, but also for operational robustness, as excessive workload and inadequate ergonomic fit can undermine quality, increase error risk, contribute to absenteeism, and introduce hidden instability into production systems that otherwise appear efficient according to traditional Lean metrics (Westgaard & Winkel, 2011; Westgaard, 2014).

Human factors research has long established that musculoskeletal disorders (MSDs) are influenced by both physical exposures—such as force, posture, and repetition—and organizational or psychosocial demands, including time pressure and sustained work intensity (Punnett & Wegman, 2004; da Costa & Vieira, 2010). In Lean environments, this dual exposure profile is particularly salient. Standardized work, takt-driven pacing, and real-time performance monitoring can elevate cognitive and temporal demands, while repetitive task structures and limited recovery opportunities may sustain physical effort and biomechanical loading (Hasle et al., 2012; Westgaard & Winkel, 2011). However, empirical studies often examine psychosocial workload and physical ergonomics separately, limiting the ability to understand how cognitive demands and physical effort combine to shape musculoskeletal outcomes, particularly when symptoms interfere with the ability to perform work activities.

These questions are especially relevant in rapidly industrializing, export-oriented contexts where Lean deployment is often accelerated to meet global competitiveness targets and where the integration of ergonomics into production design may vary across firms and sectors. Morocco provides a relevant empirical setting in this respect. Over the past decade, the country has positioned itself as a major industrial hub within global value chains, with national industrial strategies prioritizing sectors such as automotive, aeronautics, and textile and leather manufacturing (Ministry of Industry and Trade, Morocco; El Mokri, 2016). The automotive sector, in particular, has become a leading export engine and a cornerstone of industrial development, reflecting increasing production volumes and deep integration into international markets (Amachraa, 2023). Recent expansions in automotive and aeronautics further illustrate the intensity of performance requirements and operational pressure characteristic of globally connected manufacturing environments (Eljechtimi, 2024a, 2024b).

Within this context, the present study examines workload-related health outcomes in Lean industrial environments using validated and internationally recognized measures. Cognitive workload and perceived physical effort are considered complementary dimensions of workload exposure, while musculoskeletal outcomes are approached from a functional perspective that emphasizes work-limiting symptoms rather than symptom presence alone. Integrating these dimensions within a single analytical framework provides a technically grounded approach to quantifying human load in Lean systems while maintaining comparability across sectors and settings.

Figure 1 summarizes the conceptual problem addressed in this study, illustrating how Lean work system characteristics shape cognitive and physical workload demands that may contribute to work-limiting musculoskeletal outcomes.

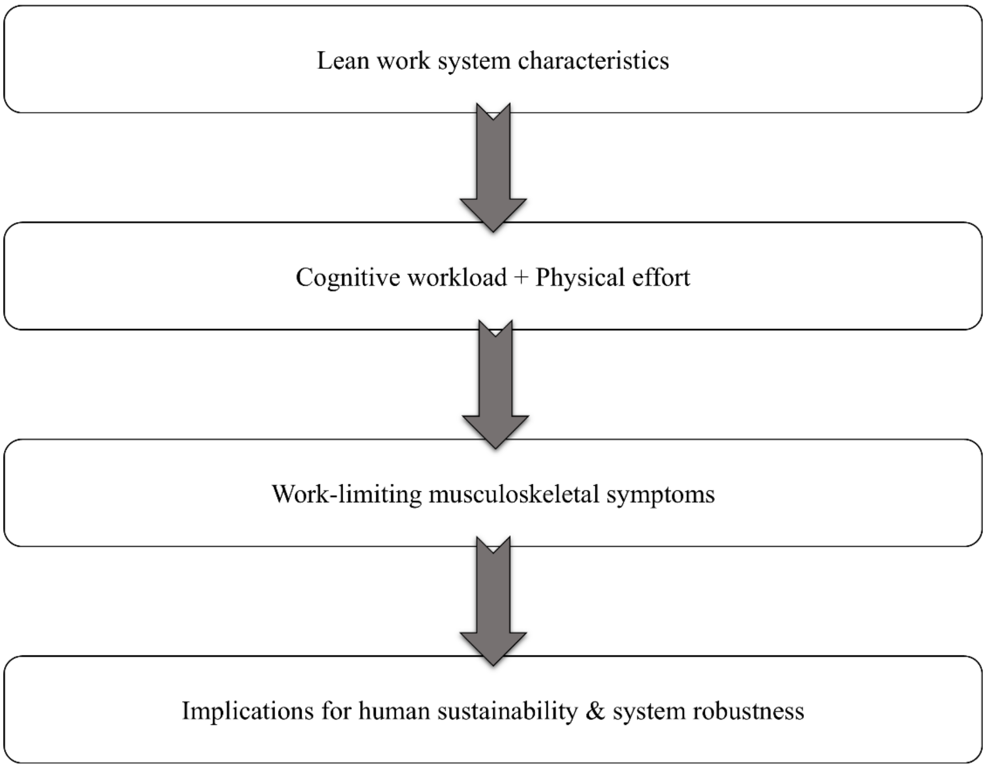

Figure 1. Conceptual representation of workload exposure and work-limiting musculoskeletal outcomes in Lean work systems

The originality of this work lies in integrating cognitive workload, perceived physical effort, and work-limiting musculoskeletal outcomes within a unified analytical approach tailored to Lean production realities, and in estimating these associations using multivariable modeling that accounts for professional seniority. This approach responds directly to persistent gaps in the Lean–work environment literature, where integrated workload–health modeling remains limited despite repeated calls for sustainable production systems that explicitly incorporate human factors (Hasle et al., 2012; Westgaard, 2014). By framing Morocco as an empirically rich example of export-oriented Lean adoption rather than as a narrow special case, the study contributes to a broader understanding of how Lean implementation conditions may shape human sustainability and operational resilience in globally connected manufacturing systems. Accordingly, this study examines the associations between cognitive workload, perceived physical effort, and work-limiting musculoskeletal symptoms in Lean industrial environments.

II. Methods

a. Study design and research approach

This study adopts a cross-sectional research design based on a structured questionnaire administered to employees working in Lean industrial environments. The research follows an exposure–outcome analytical approach, in which human workload exposure is examined in relation to musculoskeletal disorder occurrence within the context of Lean production systems. The design is consistent with prior occupational ergonomics and human factors research investigating workload-related health outcomes in industrial work systems.

b. Study context and sample

Data were collected from employees working in industrial organizations implementing Lean manufacturing practices. To ensure relevance to the research framework, a screening question was used to confirm exposure to Lean environments: "Does your organization currently implement Lean manufacturing practices (e.g., continuous improvement, standardized work, Kaizen, waste reduction, visual management)?" Only respondents answering "Yes" were retained for analysis.

A total of 150 valid responses were included in the final sample. Participants were drawn from multiple industrial sectors, reflecting heterogeneity in Lean production contexts. Data collection relied on direct professional contact and online dissemination through professional networks and digital platforms, allowing voluntary participation by individuals actively engaged in Lean work environments.

c. Data collection procedure

Data were collected between October 2025 and February 2026. The questionnaire was self-administered and distributed both through direct professional sharing and online channels. Participation was entirely voluntary.

The questionnaire was provided in English and French, allowing respondents to complete the survey in the language with which they were most comfortable. Only validated versions of measurement instruments were used. When established French versions of standardized tools were available, they were employed without modification; no ad hoc translation of measurement items was conducted by the authors.

The survey was anonymous, and no personal or organizational identifying information was collected. At the beginning of the questionnaire, participants were informed of the academic purpose of the study, the voluntary nature of participation, and their right to decline or withdraw. Consent to participate was obtained through an explicit confirmation item prior to accessing the questionnaire:

d. Measures and variables

Cognitive workload: was measured using the NASA Task Load Index (NASA-TLX). The instrument assesses perceived mental workload across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. Responses were recorded using a 7-point Likert scale. A global cognitive workload score was computed by averaging the six items, consistent with established applications of the NASA-TLX in occupational and industrial contexts.

Physical effort: was assessed using the Borg Category Ratio Scale (CR-10). Participants were asked to rate the overall level of physical exertion experienced during their usual work activities. The CR-10 scale ranges from 0 "nothing at all" to 10 "maximal", providing a validated measure of perceived physical effort that integrates force, repetition, and postural demands.

Musculoskeletal disorder occurrence: were assessed using selected items from the Nordic Musculoskeletal Questionnaire (NMQ), a widely validated instrument for the assessment of work-related musculoskeletal symptoms across multiple body regions (Kuorinka et al., 1987). Participants reported the presence or absence of musculoskeletal symptoms across predefined body regions using binary response options (0 = no, 1 = yes). Based on these responses, two complementary variables were derived. MSD_Count represented the total number of body regions with reported musculoskeletal symptoms and was used as a continuous indicator of overall symptom burden. In addition, MSD_WorkLimiting_Any was defined as a binary variable indicating whether at least one reported musculoskeletal symptom limited the participant's ability to perform work activities (1 = yes, 0 = no). The latter variable was selected as the primary dependent variable in regression analyses in order to capture occupationally meaningful functional impairment, rather than symptom presence alone. This approach is consistent with occupational health research emphasizing functional limitation and work ability as more relevant outcomes for evaluating the impact of workload exposure on sustainable work systems (Punnett & Wegman, 2004; da Costa & Vieira, 2010).

Control variables: sector of activity, professional seniority and job position were included as control variables to account for contextual differences in task structure, exposure profiles, and responsibility levels across Lean work environments. These variables were used solely for adjustment purposes and were not treated as focal constructs in the analytical model.

e. Data analysis

Data analysis was conducted using JASP statistical software. Descriptive statistics were computed to characterize the sample and summarize cognitive workload, physical effort, and musculoskeletal outcomes. Bivariate correlations were examined to explore associations between cognitive workload, physical effort, and musculoskeletal symptom burden, using the continuous variable MSD_Count.

Logistic regression analysis was then performed to estimate the likelihood of experiencing at least one work-limiting musculoskeletal symptom (MSD_WorkLimiting_Any) as a function of cognitive workload and physical effort, while controlling for professional seniority as a theoretically relevant covariate. Seniority was included due to its established role as a proxy for cumulative exposure to physical and organizational demands over the working life course (Punnett & Wegman, 2004; da Costa & Vieira, 2010).

Other contextual variables, including sector of activity and job position, were examined descriptively but were not included as covariates in the regression models in order to preserve model parsimony and avoid overadjustment. In addition, exploratory group comparisons were conducted to describe differences in workload exposure across seniority categories using analysis of variance (ANOVA). These exploratory analyses were conducted for descriptive and interpretative purposes only and were not used for model building.

III. Results and discussion

a. Sample characteristics

The final sample consisted of 150 respondents employed in industrial and engineering-related organizations operating under Lean manufacturing environments. All participants confirmed the implementation of Lean practices within their organizations through a screening question.

Respondents represented a wide range of industry sectors, including automotive, aeronautics, agri-food, textile and clothing, energy and environmental services, electrical and electronic industries, and engineering services. This sectoral diversity reflects the heterogeneous nature of contemporary Lean implementations across manufacturing and technical service contexts.

The sample included participants occupying various job positions, ranging from operational and technical roles to coordination, engineering, and managerial functions. Levels of seniority varied across respondents, capturing early-career, mid-career, and highly experienced professionals.

This diversity in sector affiliation, job position, and seniority supports the relevance of the sample for examining variations in human workload exposure and musculoskeletal outcomes within Lean-oriented work systems.

b. Descriptive statistics

Table I presents the characteristics of the study sample. The analysis included 150 respondents drawn from multiple industrial sectors operating under Lean manufacturing environments, with representation across technical, supervisory, and managerial positions and varying levels of seniority.

Table I. Sample characteristics of the study participants

Variable	Category	Frequency	Percent
Industry	Automotive	52	34.7
	Aeronautics / Aerospace	28	18.7
	Engineering / Services	24	16.0
	Textile / Clothing	18	12.0
	Agri-food	12	8.0
	Electronics / Electrical	10	6.7
	Energy / Environment	6	4.0
Position	Operator	25	16.7
	Technician	35	23.3
	Engineer	45	30.0
	Supervisor	25	16.7
	Manager	20	13.3
Seniority	< 2 years	13	8.7
	2 – 5 years	47	31.3
	6 – 10 years	58	38.7
	> 10 years	32	21.3
MSD_Any	No (0)	3	2.0
	Yes (1)	147	98.0

As shown in Table I, participants were distributed across several industry sectors, with automotive, aeronautics/aerospace, and engineering services being the most represented. The sample also covered a range of job positions, including engineers, technicians, operators, supervisors, and managers. Seniority levels varied from early-career professionals to highly experienced employees. A large majority of respondents reported at least one musculoskeletal symptom during the reference period.

Table II summarizes the descriptive statistics for the main study variables related to cognitive workload, physical effort, and musculoskeletal symptom burden (MSD_Count).

Table II. Descriptive statistics of the main study variables

	Mean	Standard deviation	Minimum	Maximum
Cognitive_Workload	5.310	0.261	4.500	5.833
Physical_Effort	4.567	1.811	1.000	9.000
MSD_Count	6.047	3.622	0.000	13.00

On average, respondents reported moderate-to-high levels of cognitive workload and moderate physical effort. The mean number of reported musculoskeletal symptoms indicates a substantial symptom burden within the sample. Observed variability suggests differences in workload exposure and symptom experience across respondents.

The descriptive results indicate substantial exposure to both cognitive workload and physical effort across the sample, alongside a high prevalence of work-limiting musculoskeletal symptoms. This pattern reflects the intensive nature of work organization in Lean production environments, where performance requirements may generate sustained cognitive and physical demands rather than isolated exposures.

c. Correlation analysis

Bivariate correlations were computed to examine associations between cognitive workload, physical effort, and musculoskeletal symptom count.

Table III. Pearson correlations among cognitive workload, physical effort, and musculoskeletal symptom count

Variables	Pearson's r	p	95% CI
Cognitive_Workload → Physical_Effort	0.170	0.038	[0.010, 0.321]
Cognitive_Workload → MSD_Count	0.126	0.123	[-0.034, 0.281]

Physical_Effort → MSD_Count	0.831	< 0.001	[0.773, 0.875]

As shown in Table III, cognitive workload was weakly but significantly correlated with physical effort. Cognitive workload was not significantly associated with musculoskeletal symptom count. In contrast, physical effort showed a strong positive association with musculoskeletal symptom count.

Bivariate correlations show that higher levels of cognitive workload and perceived physical effort are associated with greater musculoskeletal symptom burden. These associations suggest that workload exposure in Lean environments is multidimensional, with cognitive and physical demands coexisting rather than operating independently.

d. Logistic regression analysis

A logistic regression model including cognitive workload, physical effort, and professional seniority was estimated to predict the likelihood of experiencing at least one work-limiting musculoskeletal symptom.

Table IV. Logistic regression model fit

Statistic	Value
ΔX^2	62.351
p	< 0.001
McFadden R^2	0.372
Nagelkerke R^2	0.505

The model showed a statistically significant improvement over the intercept-only model.

The model showed a statistically significant improvement over the intercept-only model. Multicollinearity diagnostics indicated no evidence of problematic collinearity among the predictors.

Parameter estimates from the logistic regression model are presented in Table V.

Table V. Logistic regression coefficients predicting work-limiting musculoskeletal symptoms

Predictor	Odds ratio	95% CI	p
Cognitive_Workload	0.087	[0.012, 0.622]	0.015
Physical_Effort	0.281	[0.173, 0.458]	< 0.001
Seniority (6 – 10 years)	1.261	[0.378, 4.203]	0.706
Seniority (< 2 years)	1.197	[0.156, 9.174]	0.863
Seniority (> 10 years)	2.209	[0.603, 8.090]	0.232

Cognitive workload and physical effort were significantly associated with the likelihood of experiencing work-limiting musculoskeletal symptoms, whereas seniority was not.

The logistic regression results indicate that both cognitive workload and perceived physical effort significantly increase the likelihood of experiencing at least one work-limiting musculoskeletal symptom, even after controlling for professional seniority. In contrast, seniority does not emerge as a significant predictor, suggesting that accumulated experience alone does not mitigate the health impact of sustained workload exposure in Lean work systems. These findings point to system-level work design as a key determinant of functional musculoskeletal outcomes.

e. Differences in workload exposure by seniority

Exploratory analyses were conducted to examine whether cognitive workload and physical effort differed across professional seniority categories.

Table VI. One-way ANOVA results for workload exposure by seniority

Variables	F	p	η^2
Cognitive_Workload	5.433	.001	0.100
Physical_Effort	3.747	.012	0.071

Table VII. Cognitive workload and physical effort by seniority group

Variables	Seniority	N	Mean	SD

Cognitive_Workload	< 2 years	13	5.372	0.386
	2 – 5 years	47	5.397	0.242
	6 – 10 years	58	5.302	0.232
	> 10 years	32	5.172	0.226
Physical_Effort	< 2 years	13	5.462	2.025
	2 – 5 years	47	4.319	1.901
	6 – 10 years	58	4.931	1.746
	> 10 years	32	3.906	1.445

Significant differences across seniority groups were observed for both cognitive workload and physical effort. These analyses were conducted for descriptive purposes only and were not used for model building.

Exploratory analyses reveal that cognitive workload and physical effort differ across seniority groups, indicating heterogeneous exposure patterns within Lean work systems. However, these differences do not translate into a reduced likelihood of work-limiting musculoskeletal symptoms among more senior workers, reinforcing the interpretation that exposure is driven by work organization rather than individual adaptation over time.

IV. Conclusion

This study shows that in Lean production environments, both cognitive workload and perceived physical effort significantly increase the likelihood of experiencing work-limiting musculoskeletal symptoms, independently of professional seniority. The findings demonstrate that experience alone does not protect workers from health-limiting exposure in highly standardized Lean systems, emphasizing the role of work system design rather than individual adaptation. By integrating cognitive and physical workload within a unified analytical model, this research highlights the need to address human sustainability alongside performance objectives in Lean implementation. Future research should build on these findings by examining how targeted redesign of cognitive and physical task demands can reduce health risks while preserving operational efficiency.

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