

Article

Employees' Perceptions of Organizational Readiness for Green Ergonomics: Development and Validation of the GEQ

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Abstract

Organizations face increasing pressure to reduce their environmental impact while preserving worker health, well-being, and performance. While sustainability research increasingly emphasizes organizational and human dimensions, validated tools assessing how environmental sustainability is integrated into ergonomic practice remain limited. Green ergonomics provides a systemic framework linking human factors and environmental objectives in sustainable work system design. This study aimed to develop and validate the Green Ergonomics Questionnaire (GEQ), a psychometric instrument designed to assess employees' perceptions of organizational readiness to integrate sustainability into ergonomic practice. The GEQ was developed through a structured literature review, expert evaluation, and empirical validation using data from 412 employees across multiple occupational sectors. Exploratory and confirmatory factor analyses supported a seven-factor structure including knowledge, training and organizational learning, organizational practices, perceived impacts, obstacles, organizational culture, and employee involvement. Reliability indices indicated satisfactory internal consistency ($\alpha = 0.78$ – 0.86 ; $CR = 0.80$ – 0.88), and convergent and discriminant validity were supported. Overall, the GEQ provides a structured framework to assess employees' perceptions of how environmental sustainability is embedded within ergonomic and participatory work system design processes, contributing to research at the intersection of ergonomics, sustainability management, and organizational change.

Keywords: green ergonomics; organizational readiness; sustainable work systems; questionnaire validation; employee perceptions

1. Introduction

Modern organizations operate in an era of ecological urgency, social transformation, and technological acceleration. The transition toward sustainable modes of production requires organizations to reduce their environmental footprint while safeguarding worker health, engagement, and performance. International frameworks such as the United Nations 2030 Agenda for Sustainable Development [1] and the IPCC Sixth Assessment Report [2] emphasize that sustainability cannot rely solely on technological innovation. It also requires profound changes in how work is designed, organized, and managed. Within this context, green ergonomics provides a framework for integrating human factors and environmental objectives into the design, organization, and governance of work systems [3–5].

Green ergonomics extends the foundational principles of human factors and ergonomics (HFE)—optimizing the fit between tasks, tools, environments, and organizational



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processes—by explicitly incorporating environmental performance as a design consideration [6,7]. From a macroergonomic and sociotechnical perspective, including established work-system design frameworks such as the SEIPS model [8–11], the integration of sustainability into work systems depends not only on technical solutions but also on organizational capabilities, governance mechanisms, and workforce involvement. Sustainable work systems therefore emerge from the interaction between structural arrangements, operational practices, and human competencies throughout the system life cycle—from design and procurement to maintenance and continuous improvement [6,10,11].

Despite this conceptual development, empirical tools specifically addressing the organizational integration of green ergonomics remain scarce. Existing instruments in sustainability and organizational research frequently assess environmental attitudes, corporate social responsibility orientation, or sustainability climate [12,13], but they do not explicitly capture how environmental sustainability is perceived to be embedded in work-system design, management, and everyday work practices. Moreover, many existing tools do not clearly specify the organizational level or target population for their items, which can limit interpretability and predictive value [14,15]. The absence of validated instruments grounded in an ergonomic and sociotechnical perspective restricts comparative research and the evaluation of initiatives aimed at promoting sustainable work-system design.

Importantly, the assessment of organizational sustainability capabilities often relies on employees' perceptions, as these perceptions provide valuable insight into how organizational priorities, structures, and practices are experienced and enacted in daily work. Perceptual measures are widely used in organizational and climate research to capture collective capabilities that are difficult to observe directly [16]. Similarly, organizational readiness has been conceptualized as a shared psychological and structural state reflecting members' beliefs in collective capability and commitment to implement change [17]. In this perspective, measuring employees' perceptions of organizational readiness to integrate green ergonomics can provide an informative entry point for understanding how sustainability principles are operationalized within work systems.

The present research addresses this gap by developing and validating the Green Ergonomics Questionnaire (GEQ), a psychometrically grounded instrument designed to measure employees' perceptions of organizational readiness to integrate environmental sustainability into ergonomics-related work-system design and management. The GEQ should therefore be interpreted as a perceptual organizational-level indicator rather than a direct technical audit of work-system design. The GEQ was developed through a systematic review of literature in ergonomics, psychology, and management, followed by expert evaluation and empirical validation. It proposes a multidimensional structure reflecting the interplay between individual knowledge and competencies, organizational arrangements, and operational practices that collectively shape the integration of sustainability into work systems.

Conceptually, the GEQ draws on organizational readiness-for-change frameworks [17,18], while situating readiness within a sociotechnical understanding of work systems. In this view, readiness for green ergonomics can be understood through interrelated components encompassing cognitive and motivational aspects, organizational structures and culture, and operational capabilities. These components are operationalized in seven dimensions: knowledge, training and organizational learning, organizational practices, perceived impacts, obstacles, organizational culture, and employee involvement. Together, these dimensions represent employees' perceptions of how sustainability considerations are incorporated into ergonomic design, organizational processes, and daily work activities.

Beyond ergonomics and human factors research, sustainability literature emphasizes that ecological transition requires organizations to manage tensions between environmental,

social, and economic performance [19]. Addressing these tensions requires the development of organizational capabilities that enable sustainability principles to be embedded within operational routines, managerial decision-making, and organizational learning processes [20]. From this perspective, perceived organizational readiness for green ergonomics can be interpreted as an indicator of employees' shared perceptions regarding the organization's capability to integrate environmental objectives into work-system design and governance. Unlike general sustainability climate or green HRM measures, the GEQ specifically focuses on the perceived integration of environmental sustainability into work-system organization, design, and operational practices. While several sustainability maturity frameworks exist, measurement tools capturing this capability at the intersection of human factors and sustainability management remain limited [21].

Practically, the GEQ is intended to support ergonomics and sustainability initiatives at multiple stages: identifying perceived strengths and barriers, informing participatory design and prioritization processes, and monitoring organizational progress over time. By linking employees' perceptions with system-level design processes, the GEQ provides a structured approach for supporting both research and practice in the development of sustainable work systems.

From a theoretical standpoint, this study contributes by proposing an initial operationalization of perceived organizational readiness for green ergonomics grounded in a sociotechnical perspective. Rather than measuring objective system characteristics directly, the GEQ captures employees' perceptions of organizational capabilities to integrate sustainability into work systems. This positioning complements existing research on sustainability climate, organizational readiness, and pro-environmental practices by focusing specifically on the work-system and human-factors interface. In doing so, the study contributes to the understanding of how sustainability transition processes are experienced within organizational work systems and provides a foundation for future multimethod research combining perceptual, observational, and performance-based indicators.

2. Materials and Methods

The development of the Green Ergonomics Questionnaire (GEQ) followed a multi-phase, theory-driven process consistent with recommended practices for instrument design and scale validation [14,15]. The objective was to construct a psychometrically sound and operationally relevant tool to assess employees' perceptions of organizational readiness for green ergonomics, understood as the integration of environmental sustainability principles into the design, management, and operation of work systems. The methodology combined a theoretical foundation in ergonomics and human factors with statistical validation procedures to ensure both conceptual relevance and practical usability.

2.1. Item Development

The item generation phase was grounded in ergonomics, human factors, and sustainability science. The conceptual framework was inspired by ISO 6385:2016 [6], macroergonomic theory [8,9], and green ergonomics [3–7]. These perspectives share a common principle: effective and sustainable work systems emerge from the joint optimization of human, organizational, and environmental performance. In this study, readiness for green ergonomics was therefore conceptualized as a systemic construct reflected in employees' perceptions of how sustainability is integrated into organizational practices, culture, and decision-making processes.

The synthesis of these frameworks led to the identification of seven interrelated dimensions characterizing the integration of green ergonomics in organizations: knowledge, training and organizational learning, organizational practices, perceived impacts, obsta-

cles, organizational culture, and employee involvement. The “Knowledge” dimension reflects employees’ perceived understanding of sustainable ergonomic principles and their implications for work-system design. The “Training and Organizational Learning” dimension refers to the perceived availability, relevance, and organizational support of learning opportunities (e.g., training, knowledge sharing, feedback loops) that foster sustainability-oriented ergonomic competencies. “Organizational Practices” capture employees’ perceptions of formalized procedures, routines, and resource-management practices through which environmental sustainability is integrated into day-to-day work organization and ergonomic processes. “Perceived Impacts” reflect employees’ evaluations of expected or observed outcomes in terms of well-being, efficiency, and environmental benefits. “Obstacles” refer to perceived structural, organizational, or operational barriers that may hinder implementation. “Organizational Culture” addresses shared values, managerial priorities, and governance mechanisms supporting sustainability integration. Finally, “Employee Involvement” reflects the perceived degree of worker participation in the design, feedback, and continuous improvement of environmentally and ergonomically sustainable work systems.

An initial pool of 35 items was generated to represent these seven dimensions in a balanced way between individual-level experiences and organizational processes. Items were phrased as short, behaviorally anchored statements, avoiding abstract or overly technical vocabulary to ensure accessibility for respondents without expertise in ergonomics. For instance, statements such as “Environmental criteria are considered during workstation redesign” or “My organization encourages the reuse or recycling of work materials” were typical formulations. All items were rated on a five-point Likert scale ranging from 1 (“strongly disagree”) to 5 (“strongly agree”). This format was chosen to capture agreement with statements describing perceived organizational practices and conditions across diverse contexts.

All items were initially developed and validated in French to ensure linguistic and cultural adequacy for the target population. The finalized 32-item Green Ergonomics Questionnaire (GEQ), developed in French and translated into English for reference, is presented in Appendix A.

The theoretical alignment of items was further examined by mapping them onto (i) established sociotechnical and ergonomic work-system design frameworks (e.g., ISO 6385 and SEIPS) [6,10] and (ii) widely used behavior and motivation frameworks relevant to pro-environmental practices at work (e.g., the Theory of Planned Behavior and self-determination theory) [22,23]. This comparison ensured that the GEQ captures perceptions related specifically to work-system design and organizational processes, rather than general environmental attitudes.

2.2. Expert Review

A qualitative validation phase was conducted with a panel of eight experts selected for their complementary expertise in ergonomics, human factors, and sustainability management. The panel included academic ergonomists specializing in cognitive, physical, and organizational ergonomics, professional ergonomists involved in industrial system design, sustainability managers experienced with ISO 14001 environmental management systems, and a social psychologist specializing in pro-environmental organizational behavior. Each expert had more than ten years of professional or research experience and at least one peer-reviewed publication in ergonomics or sustainability.

Experts individually reviewed the 35-item version of the questionnaire and participated in semi-structured interviews of approximately 45 min each. They evaluated conceptual relevance, wording clarity, and theoretical coverage of the items in relation to the

seven proposed dimensions. Feedback was analyzed thematically, leading to refinement of several formulations, elimination of redundant or ambiguous items, and consolidation of conceptual overlaps. This phase confirmed the relevance of the seven dimensions and resulted in a refined 32-item version.

2.3. User Pre-Test

Following the expert phase, a user pre-test was conducted with 30 employees from manufacturing, healthcare, services, and public administration sectors. The objective was to verify comprehension, wording clarity, and usability among respondents without specialized ergonomic knowledge. Participants completed the 32-item version online and subsequently took part in short debriefing interviews. Results indicated very good comprehension and ease of response, with 93% of participants judging the items as “clear” or “very clear”. Minor linguistic simplifications were made to replace technical terms with more accessible expressions. This phase supported the face validity and practical accessibility of the GEQ for its intended audience.

2.4. Participants and Data Collection

The study sample comprised 412 participants recruited across multiple occupational sectors and organizational contexts.

As presented in Table 1, the sample showed a balanced gender distribution, with a slight predominance of male participants (53.9%) compared with female participants (43.4%), while 2.7% of respondents identified as other or preferred not to disclose their gender. The mean participant age was 40.48 years (SD = 9.81), with the majority of respondents aged between 30 and 44 years (52.7%), followed by 45–59 years (32.0%). Younger workers aged 18–29 years represented 13.1% of the sample, while participants aged 60 years or older represented 2.2%.

Table 1. Sociodemographic Characteristics of the Sample (N = 412).

Variable	Category	n	%
Gender	Male	222	53.9
	Female	179	43.4
	Other/Prefer not to disclose	11	2.7
Age Group	18–29	54	13.1
	30–44	217	52.7
	45–59	132	32.0
	≥60	9	2.2

Occupational and organizational characteristics are summarized in Table 2. Participants were employed across diverse sectors, including services (38.8%), manufacturing (27.2%), healthcare and medico-social services (18.0%), and public institutions (16.0%). The sample included employees from multiple hierarchical levels, with frontline workers representing the majority (51.9%), followed by supervisors (31.3%) and managers (16.7%). Regarding organizational context, participants were distributed across organizations of varying sizes, including small enterprises (<50 employees, 26.2%), medium-sized organizations (50–250 employees, 39.3%), and large organizations (>250 employees, 34.5%). This heterogeneity supports the external validity of the GEQ and ensures sufficient variability for psychometric validation across diverse work environments.

Table 2. Occupational and Organizational Characteristics (N = 412).

Variable	Category	n	%
Sector of Activity	Services	160	38.8
	Manufacturing	112	27.2
	Healthcare and medico-social services	74	18.0
	Public sector	66	16.0
Job Level	Operator/Employee	214	51.9
	Supervisor	129	31.3
	Manager	69	16.7
Organization Size	<50 employees	108	26.2
	50–250 employees	162	39.3
	>250 employees	142	34.5

This diversity across sectors, job levels, and organization sizes provides sufficient variability for psychometric validation and is consistent with recommended practices in scale development studies [14,15].

2.5. Psychometric Analyses

All analyses were conducted using R version 4.3.2 with the psych and lavaan packages [24,25]. The validation followed a two-step approach. First, an Exploratory Factor Analysis (EFA) examined the latent structure of the questionnaire. Sampling adequacy was assessed using the Kaiser–Meyer–Olkin index (KMO > 0.80) and Bartlett’s test of sphericity ($p < 0.001$). Principal-axis factoring with oblimin rotation was applied to allow for factor intercorrelations, and the number of factors was determined using scree plot inspection and parallel analysis.

Second, a Confirmatory Factor Analysis (CFA) tested the hypothesized seven-factor model using robust maximum likelihood estimation (MLR). Model fit was evaluated using standard indices including the Comparative Fit Index (CFI), Tucker–Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR), following Hu and Bentler [26].

To examine whether the GEQ reflects an overall perceived organizational readiness construct, an additional higher-order CFA model was tested with the seven dimensions loading onto a global factor.

Internal consistency was estimated using Cronbach’s alpha and Composite Reliability, while convergent validity was assessed through the Average Variance Extracted (AVE). Discriminant validity was evaluated using the HTMT ratio. Potential common method bias was examined using Harman’s single-factor test.

2.6. Ethical Considerations

All study procedures complied with the ethical principles outlined in the Declaration of Helsinki and relevant institutional guidelines. Participation was voluntary and anonymous. Prior to participation, respondents were informed about the study objectives, the confidentiality of their responses, and their right to withdraw at any time without penalty. Informed consent was obtained from all participants before data collection.

In accordance with national regulations and institutional guidance for anonymous, non-interventional questionnaire studies involving adults and non-sensitive data, formal ethics committee/IRB approval was not required. All data were collected and stored securely, ensuring confidentiality and exclusive use for research purposes.

2.7. Use of Generative AI Tools

Generative artificial intelligence (AI) was not used to generate data, perform analyses, or draft substantive scientific content. Assistance was limited to grammar, spelling, and format checking during manuscript preparation.

3. Results

Consistent with the multidimensional readiness framework presented in the introduction, the analyses aimed to confirm whether the seven dimensions empirically capture the psychological, structural, and practical components of organizational readiness for green ergonomics as reflected in employees' perceptions of organizational practices and conditions. The sample was randomly split into two subsamples ($n = 206$ each) to conduct independent exploratory and confirmatory analyses, ensuring cross-validation of the measurement model.

3.1. Definition and Expert Validation of Dimensions and Items

Before initiating the empirical validation, a comprehensive conceptual and ergonomic assessment was carried out to ensure that the Green Ergonomics Questionnaire (GEQ) accurately reflected the principles of human factors and ergonomics (HFE) and the systemic orientation of green ergonomics. This phase focused on verifying the theoretical consistency, ergonomic relevance, and linguistic clarity of both the dimensions and the initial 35 items.

Eight experts participated in this stage, selected for their complementary expertise in ergonomics, work-system design, and environmental sustainability. The panel included three academic ergonomists specializing in sustainable work design and macroergonomics, two professional ergonomists engaged in large-scale industrial transformation projects, two corporate sustainability managers overseeing environmental initiatives, and one occupational health researcher experienced in behavioral change at work. This interdisciplinary composition ensured that both theoretical and applied dimensions of green ergonomics were represented.

Experts were provided with a detailed conceptual framework describing the seven initial dimensions—knowledge, training and organizational learning, organizational practices, perceived impacts, obstacles, organizational culture, and employee involvement—alongside the 35 proposed items. They were asked to assess each item's clarity, conceptual relevance, and correspondence to ergonomic principles as defined in ISO 6385 (2016) and the macroergonomic literature [6,8,9], as well as their ability to reflect organizational readiness through employee-level responses.

The experts confirmed the overall relevance of the seven theoretical dimensions but suggested several refinements to strengthen the systemic orientation and ensure the instrument's applicability to a general workforce. Specifically, they recommended shifting the focus from individual environmental behaviors to organizational processes that reflect systemic design logic, thereby reinforcing the link between individual perceptions and organizational-level readiness. Consequently, the "Practices" dimension was renamed Organizational Practices, emphasizing collective procedures, work organization, and resource management rather than personal actions. Similarly, the "training and organizational learning" dimension was broadened to Training and Organizational Learning, integrating aspects of knowledge sharing, collective competence building, and managerial support.

Across the 35 initial items, nine were substantively revised, three were merged, and four were removed due to redundancy or limited ergonomic relevance. Most changes targeted lexical simplification, improved specificity, and the inclusion of concrete examples that could be easily understood by employees without formal ergonomics training. For instance, "I apply eco-responsible actions in my daily tasks" was reformulated as "I

contribute to reducing environmental impact through my work organization and task methods”. Likewise, overly technical expressions such as “environmental optimization of workstations” were simplified to “improvement of workstations to reduce environmental impact”. Following these refinements, the questionnaire comprised 32 items distributed across the seven validated dimensions, representing a balanced articulation between individual perceptions, collective practices, and systemic integration. This expert validation established a strong conceptual foundation for the subsequent phases of qualitative and psychometric testing, supporting the interpretation of GEQ responses as indicators of perceived organizational readiness.

3.2. Qualitative Pre-Tests

After expert validation, two qualitative pre-tests were conducted to verify the accessibility and ecological validity of the GEQ items. First, the expert panel reviewed the revised 32-item version to confirm conceptual alignment and respondent readability. Overall, experts rated content validity as high, with 87% of items judged as clear and directly relevant, and minor revisions were made to reduce redundancy and improve wording clarity (Table 3). Second, a user pre-test was conducted with 30 professionals from diverse sectors (manufacturing, healthcare, services, and public administration) to ensure comprehensibility among respondents without specialized training in ergonomics or sustainability. Most participants rated the items as clear or very clear (93%) and considered the response scale easy to use (89%). Minor lexical simplifications were introduced—mainly in the Organizational Practices and Training and Organizational Learning dimensions—to further enhance accessibility. The final 32-item version was retained for psychometric validation.

Table 3. Summary of expert feedback and adjustments made to the initial item pool.

Issue Identified	Type of Modification	Example of Adjustment
Lexical ambiguity	Rewording for clarity	“Eco-responsible actions” → “environmentally sustainable practices”
Redundancy	Item removed	Two similar items merged in Organizational Practices
Overly technical wording	Simplified phrasing	“Environmental optimization of workstations” → “improvement of workstations to reduce environmental impact”
Lack of behavioral examples	Example added	Added reference to recycling or energy use behaviors

3.3. Exploratory Factor Analysis (EFA)

The first quantitative stage aimed to examine the latent structure of the GEQ and assess empirical support for the proposed multidimensional framework. Sampling adequacy and common method diagnostics are reported in Table 4.

Table 4. Sampling adequacy, parallel analysis, and common method diagnostics.

Statistic	Value
KMO overall	0.912
Bartlett chi2	2830.412
Bartlett df	496
Bartlett p	$p < 0.001$
Parallel analysis n factors	6.000
Harman one factor variance prop	0.278

The Kaiser–Meyer–Olkin index indicated excellent sampling adequacy ($KMO = 0.912$), and Bartlett’s test of sphericity was highly significant ($p < 0.001$), confirming the suitability of the data for factor analysis.

Parallel analysis suggested a six-factor solution, whereas inspection of the scree plot and the theoretically specified readiness framework supported retaining seven factors. The seven-factor solution was retained because it (i) preserved the conceptual coverage of the theorized readiness components, (ii) yielded a clearer simple structure, and (iii) was subsequently supported by CFA and the second-order model. Although the seventh factor eigenvalue was only marginally above the random-data threshold, the corresponding item set formed a conceptually coherent dimension, supporting its retention. In addition, the seven-factor solution yielded fewer and less interpretable cross-loadings than the six-factor solution.

The eigenvalues and proportion of variance explained by each factor are presented in Table 5. The seven retained factors accounted for 63.16% of the total variance. The first factor explained 29.99% of the variance, followed by progressively smaller contributions from the remaining six factors. This level of cumulative explained variance is considered satisfactory for multidimensional organizational constructs and supports the adequacy of the retained factor structure.

Table 5. Total Variance Explained (Exploratory Factor Analysis).

Factor	Eigenvalue	% of Variance	Cumulative %
F1	9.60	29.99	29.99
F2	2.37	7.40	37.39
F3	2.15	6.71	44.10
F4	1.80	5.63	49.73
F5	1.61	5.03	54.76
F6	1.48	4.62	59.37

The scree plot illustrating the eigenvalue distribution is presented in Figure 1.

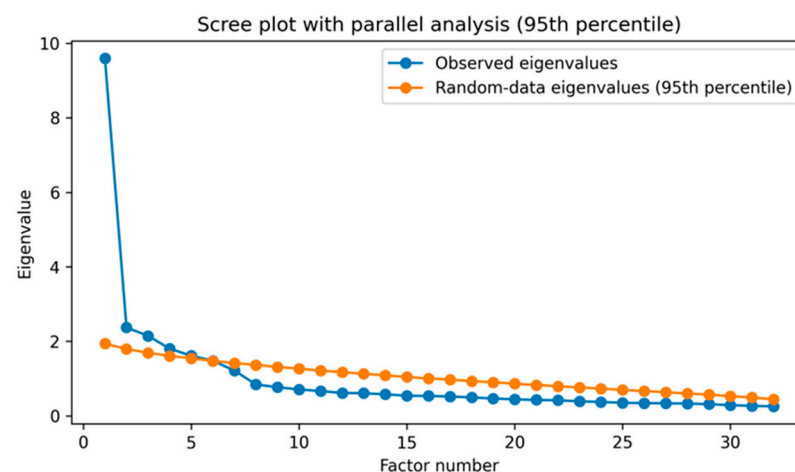


Figure 1. Scree plot with parallel analysis supporting a seven-factor solution.

Together, the retained factors explained a substantial proportion of total variance, consistent with expectations for multidimensional organizational constructs.

Representative standardized factor loadings are reported in Table 6 for readability; the full pattern matrix for all items is provided in Supplementary Table S1.

Table 6. Exploratory factor loadings (principal axis factoring, oblimin rotation).

Item	F1	F2	F3	F4	F5	F6	F7
GEQ01	−0.071	0.074	0.082	0.459	0.039	−0.19	0.201
GEQ02	0.14	−0.012	−0.006	0.623	0.027	0.089	0.139
GEQ03	0.021	0.049	0.047	0.698	−0.014	−0.088	−0.027
GEQ04	−0.016	−0.092	0.015	0.739	−0.049	−0.072	−0.056
GEQ05	0.046	−0.075	−0.015	0.653	0.106	0.066	0.018
GEQ06	0.01	−0.095	−0.038	0.046	−0.037	−0.7	0.005
GEQ07	0.139	−0.088	0.035	0.063	−0.019	−0.597	−0.099
GEQ08	0.071	0.007	0.007	−0.039	0.122	−0.679	0.05
GEQ09	−0.055	0.073	0.102	0.046	0.04	−0.632	0.053
GEQ10	0.078	−0.084	0.658	−0.104	−0.094	−0.072	0.023
GEQ11	0.037	−0.059	0.757	0.046	0.069	0.033	−0.047
GEQ12	−0.048	0.062	0.724	0.115	0.012	−0.025	0.055
GEQ13	−0.136	0.076	0.516	0.057	0.198	−0.079	0.142
GEQ14	0.055	−0.056	0.781	−0.034	−0.017	−0.007	0.032
GEQ15	−0.019	−0.061	0.015	0.032	0.094	−0.019	0.652
GEQ16	0.08	−0.007	0.014	0.016	−0.035	0.013	0.73
GEQ17	0.083	−0.134	−0.01	0.057	−0.013	0.015	0.441
GEQ18	0.005	−0.063	0.109	−0.017	0.005	−0.049	0.604
GEQ19	0.007	0.016	0.011	0.008	−0.754	0.025	−0.044

Note. Table 6 reports a subset of items for readability (representative loadings). The full 32-item pattern matrix is provided in Supplementary Table S1.

Overall, items showed meaningful loadings on their intended dimensions, with limited cross-loadings, supporting the structural coherence of the proposed model. To assess potential common method bias, Harman's single-factor test was performed. The first unrotated factor accounted for 27.8% of total variance, well below the 50% threshold, suggesting that common method variance was unlikely to substantially bias the results.

3.4. Confirmatory Factor Analysis (CFA)

To validate the structure identified in the exploratory phase, confirmatory factor analyses were conducted on the second subsample. Model fit indices for competing measurement models are reported in Table 7.

Table 7. Comparison of CFA model fit indices for alternative measurement models.

Model	DoF	Chi2	<i>p</i> -Value	CFI	TLI	RMSEA	SRMR	Chi2/df
Seven-factor CFA	443.000	504.314	0.023	0.975	0.972	0.026	0.053	1.138
One-factor CFA	464.000	1624.893	0.001	0.519	0.486	0.110	0.112	3.502
Second-order CFA	457.000	523.131	0.017	0.973	0.970	0.027	0.058	1.145

The hypothesized seven-factor model demonstrated very good fit to the data (CFI = 0.975, TLI = 0.972, RMSEA = 0.026, SRMR = 0.053), indicating that the multidimensional structure adequately represents perceived organizational readiness for green ergonomics. In contrast, the one-factor model showed poor fit (CFI = 0.519, RMSEA = 0.110), confirming that the GEQ does not reflect a unidimensional construct.

Because organizational readiness was conceptualized as a systemic capability, a second-order CFA model was also tested. This model also demonstrated good fit (CFI = 0.973, RMSEA = 0.027), comparable to the first-order model, supporting the interpretation that the seven dimensions can be viewed as both distinct components and indicators of an overarching readiness construct.

A graphical comparison of model fit indices is shown in Figure 2.

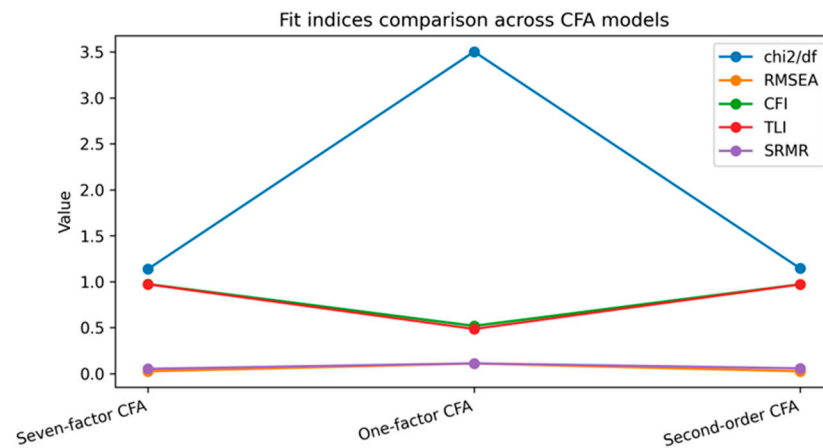


Figure 2. Comparison of CFA model fit indices across alternative measurement models.

Standardized factor loadings were generally high and statistically significant, confirming stable relationships between items and latent constructs.

3.5. Reliability and Validity

Internal consistency and convergent validity indices for each dimension are presented in Table 8.

Table 8. Reliability and convergent validity indices (Cronbach's alpha, CR, AVE).

Dimension	K Items	Cronbach Alpha	Composite Reliability CR	Average Variance Extracted AVE	Std Loading Min	Std Loading Max
Knowledge	5.000	0.824	0.825	0.485	0.680	0.712
Training and Organizational Learning	4.000	0.808	0.808	0.513	0.699	0.744
Organizational Practices	5.000	0.863	0.864	0.560	0.708	0.797
Perceived Impacts	4.000	0.766	0.768	0.454	0.590	0.704
Obstacles	4.000	0.785	0.786	0.480	0.649	0.748
Organizational Culture	4.000	0.819	0.819	0.531	0.704	0.741
Employee Involvement	6.000	0.855	0.855	0.496	0.673	0.733

Cronbach's alpha values ranged from 0.766 to 0.863, indicating satisfactory internal consistency across dimensions. Composite reliability values were all above 0.75, further supporting construct reliability. Average variance extracted (AVE) values were above 0.50 for several dimensions and slightly below this threshold for others (e.g., Perceived Impacts, Obstacles, Employee Involvement). However, because composite reliability remained adequate and factor loadings were substantial, convergent validity was considered acceptable.

Discriminant validity was evaluated using the heterotrait–monotrait ratio (HTMT), reported in Table 9.

Table 9. HTMT matrix for discriminant validity assessment.

	KNO	TOL	OPR	IMP	OBS	CUL	INV
KNO	—	0.46	0.49	0.45	0.34	0.46	0.45
TOL		—	0.42	0.43	0.50	0.36	0.30
OPR			—	0.33	0.35	0.39	0.33
IMP				—	0.52	0.32	0.45
OBS					—	0.30	0.41
CUL						—	0.36
INV							—

Note. KNO = Knowledge; TOL = Training and Organizational Learning; OPR = Organizational Practices; IMP = Perceived Impacts; OBS = Obstacles; CUL = Organizational Culture; INV = Employee Involvement.

All HTMT values were below the conservative threshold of 0.85, supporting satisfactory discriminant validity across the seven dimensions.

3.6. Summary of Psychometric Validation

Across the conceptual, qualitative, and quantitative stages, the GEQ demonstrated a stable and theoretically interpretable multidimensional structure. Confirmatory analyses indicated very good model fit for both the seven-factor and the second-order solutions, supporting the interpretation of the dimensions as distinct yet related components of employees' perceptions of organizational readiness for green ergonomics. Reliability indices were satisfactory across dimensions, convergent validity was generally acceptable given adequate composite reliability and substantial standardized loadings, and discriminant validity was supported by HTMT criteria. Taken together, these findings provide empirical support for the GEQ as a psychometrically sound instrument to examine how environmental sustainability is perceived to be embedded within ergonomics and participatory work-system design processes.

4. Discussion

The present study aimed to develop and validate the Green Ergonomics Questionnaire (GEQ), a multidimensional instrument designed to assess employees' perceptions of organizational readiness to integrate sustainability principles into ergonomics practice. Grounded in human factors and ergonomics (HFE) theory, the GEQ operationalizes the systemic perspective of green ergonomics by capturing perceived psychological, structural, and practical conditions that influence how organizations adopt environmentally sustainable work practices. The results confirmed the hypothesized seven-factor structure—knowledge, training and organizational learning, organizational practices, perceived impacts, obstacles, organizational culture, and employee involvement—providing empirical support for a comprehensive perceptual model of readiness for green ergonomics.

Beyond the validation of a measurement instrument, this study contributes to the theoretical integration of sustainability management and human factors research by demonstrating that perceived organizational readiness for environmental transition can be operationalized through a sociotechnical perspective. The findings support the view that sustainability transformation is not solely driven by technological innovation or regulatory compliance but is also shaped by organizational conditions related to knowledge development, participatory governance, and the perceived integration of sustainability criteria into work design processes [19,20]. In this regard, the GEQ provides empirical support for systemic approaches to sustainability that emphasize the interdependence between human performance, organizational structures, and environmental objectives [5,8].

This study contributes in three main ways. Firstly, it operationalizes perceived organizational readiness for green ergonomics at the intersection of sustainability management and work-system design. Secondly, it empirically supports a multidimensional sociotechnical structure through both first-order and second-order modeling. Thirdly, it provides a validated perceptual framework that complements objective sustainability and ESG indicators by capturing internal organizational conditions that may enable sustainable work-system integration.

Accordingly, the GEQ should be interpreted as an ergonomics-oriented perceptual readiness measure, rather than a generic sustainability climate or green HRM instrument. These findings directly address the problem identified in the introduction: the limited availability of validated instruments capable of assessing employees' perceptions of how environmental sustainability is integrated into ergonomics programs. Previous research has largely focused on pro-environmental attitudes or corporate sustainability climate [12,13], often neglecting the organizational and operational processes as experienced by employees that may facilitate or constrain ergonomic interventions. Unlike sustainability, climate, or green HRM scales that primarily capture general environmental orientation or policy-level

initiatives, the GEQ specifically targets perceived organizational conditions related to work-system design, ergonomic processes, and participatory governance structures. In doing so, it shifts the analytical focus from broad environmental attitudes to the perceived systemic conditions that may enable sustainability integration within everyday work practices. The GEQ advances this field by situating environmental considerations within the ergonomics framework of work-system design, governance, and participatory implementation, while explicitly measuring perceptions of these organizational conditions.

Sustainability transformation requires both individual engagement and structural capacity and often involves managing tensions between environmental, social, and economic performance objectives [19]. Perceived readiness for green ergonomics can thus be interpreted as an indicator of systemic preparedness: the extent to which employees perceive that training, work organization, and culture are aligned with environmental objectives. The associations observed between Organizational Culture and Employee Involvement highlight the role of participatory mechanisms and cultural support in shaping perceptions of sustainable change. Resource constraints, unclear procedures, and limited managerial engagement were perceived as critical barriers to embedding sustainability within ergonomics practice, reinforcing the view that sustainability transition involves organizational change affecting governance structures, learning processes, and strategic alignment [20].

Methodologically, the multi-phase validation process strengthened both the theoretical foundation and empirical robustness of the instrument. The expert review ensured ergonomic and systemic relevance, notably by reformulating items to remain accessible to non-specialist workers while preserving conceptual rigor. This balance between accessibility and scientific precision addresses the concern that employees might lack the technical expertise required to respond to system-level questions. The GEQ demonstrates that complex organizational processes can be meaningfully assessed through carefully constructed perceptual indicators that are understandable across hierarchical levels.

The findings also offer insights into organizational transformation toward sustainability. The GEQ does not measure objective environmental performance; rather, it captures how employees perceive the organizational capability to embed sustainability objectives within strategic decision-making, operational management, and workforce development policies. In this respect, the instrument may support sustainability governance by identifying perceived leverage points within organizational processes such as procurement strategies, training programs, participatory innovation initiatives, and continuous improvement systems. This perspective aligns with the sustainability management literature, which suggests that environmental transition requires embedding sustainability principles within core business processes rather than treating them as peripheral compliance activities [21,27]. It is important to clarify the conceptual boundaries of the instrument. The GEQ does not assess objective sustainability performance, environmental management maturity, or formal green HRM policies per se. Rather, it measures employees' shared perceptions of organizational conditions that may enable or constrain the integration of sustainability within ergonomic and work-system design processes. This distinction prevents conflating perceptual readiness with operational performance metrics and reinforces the positioning of the GEQ as a complementary diagnostic tool.

Furthermore, the GEQ may complement corporate sustainability reporting and internal sustainability governance by providing a human-centered indicator of perceived organizational capability to operationalize environmental strategies [21,27]. While sustainability reporting frameworks typically emphasize performance outcomes, they rarely capture the internal organizational conditions as perceived by employees that enable sustainable transformation. By assessing workforce competencies, participatory practices,

and organizational culture from the employees' perspective, the GEQ contributes to a more comprehensive understanding of sustainability maturity and may inform alignment between ergonomic programs and corporate sustainability reporting requirements.

The psychometric analyses further support the multidimensional nature of perceived organizational readiness for green ergonomics. Strong internal consistency and robust construct validity indicate that readiness perceptions cannot be reduced to individual attitudes alone but reflect shared perceptions of systemic organizational properties. These results are consistent with theoretical models of organizational readiness for change [17,18], extending them into the domain of sustainable human factors. The three readiness components identified—psychological, structural, and practical—correspond respectively to awareness and perceived impacts (knowledge, perceived impacts), governance and participation (organizational culture, employee involvement), and operational capability (training and organizational learning, organizational practices).

The GEQ provides ergonomists and sustainability professionals with a structured diagnostic and developmental framework. As a diagnostic tool, it enables assessment of perceived strengths and barriers in the integration of sustainability within ergonomic design and management. As a participatory facilitation tool, it may support dialogue between stakeholders to co-design interventions targeting identified weaknesses. As a monitoring instrument, it can enable longitudinal tracking of perceived changes following ergonomic or sustainability initiatives. In this way, the GEQ bridges measurement and organizational learning processes while remaining grounded in perceptual assessment rather than direct performance evaluation.

The theoretical and practical contributions of this research also resonate with the broader sustainability agenda. By quantifying perceived organizational readiness for sustainable ergonomics, the GEQ offers a potential complementary indicator relevant to Sustainable Development Goals (SDGs), particularly SDG 8 ("Decent Work and Economic Growth") and SDG 12 ("Responsible Consumption and Production"). Rather than replacing performance metrics, the instrument provides insight into the internal organizational conditions that may support progress toward these objectives.

Future research should examine the predictive validity of the GEQ in relation to sustainability outcomes. While the current study establishes structural validity, it does not test whether perceived readiness predicts measurable improvements in environmental performance indicators, employee well-being, or organizational efficiency. Longitudinal and intervention-based designs are needed to determine whether higher levels of perceived readiness are associated with more effective implementation of sustainability initiatives. Establishing such relationships would strengthen the theoretical positioning of green ergonomics as a sociotechnical capability supporting the sustainability transition.

Several limitations must be acknowledged. The cross-sectional design precludes causal inference, and the reliance on self-reported perceptions may be influenced by contextual factors or shared method variance. Although the sample included participants from multiple sectors, further research should test cross-cultural stability, measurement invariance, and contextual sensitivity. Multilevel analytical approaches could also clarify how perceived readiness operates across organizational levels.

The GEQ was developed and validated in French, reflecting the linguistic and cultural context of francophone professional environments. This initial validation provides a foundation for future cross-cultural adaptation and metric equivalence testing.

In conclusion, the GEQ represents an important step toward operationalizing the concept of green ergonomics within organizations through a perceptual measurement framework. It offers a validated and theoretically grounded instrument to assess and monitor employees' perceptions of organizational readiness for integrating environmen-

tal sustainability into ergonomic practices. By situating ecological considerations within work-system design and organizational processes, the GEQ contributes to advancing research at the intersection of ergonomics, sustainability management, and organizational change. Future studies should explore whether perceived readiness translates into observable sustainability outcomes and how such perceptions evolve over time during organizational transformation.

5. Conclusions

This study developed and validated the Green Ergonomics Questionnaire (GEQ), a multidimensional instrument designed to assess employees' perceptions of organizational readiness to integrate environmental sustainability into work-system design and ergonomic practices. Grounded in a sociotechnical perspective, the GEQ conceptualizes readiness not as a purely psychological or managerial attribute, but as an organizational capability reflected in how sustainability-related knowledge, organizational conditions, and operational practices are perceived within the work system.

The empirical results supported a stable seven-dimensional structure encompassing knowledge, training and organizational learning, organizational practices, perceived impacts, obstacles, organizational culture, and employee involvement. Confirmatory analyses indicated good model fit, and the reliability, convergent validity, and discriminant validity indices were generally satisfactory. Together, these findings provide evidence that the GEQ offers a coherent and psychometrically sound framework for examining how sustainability considerations are perceived and embedded in organizational work systems.

Importantly, the GEQ does not aim to measure objective environmental or ergonomic performance directly. Instead, it captures employees' perceptions of organizational conditions that may facilitate or hinder the integration of sustainability into work design and management processes. In this respect, the instrument complements existing approaches in sustainability, climate, and organizational readiness research by focusing specifically on the intersection between environmental sustainability and work-system design. This perspective emphasizes the role of human and organizational factors in supporting ecological transitions while acknowledging that a comprehensive evaluation of green ergonomics requires combining perceptual measures with observational and system-level assessments.

From a practical standpoint, the GEQ may assist organizations in identifying perceived strengths and barriers related to sustainable work-system integration, supporting participatory diagnosis, guiding intervention priorities, and monitoring organizational change over time. By providing a structured view of readiness across multiple organizational dimensions, the instrument can help practitioners and decision-makers better align sustainability objectives with operational work practices and ergonomic design processes.

Several limitations should be acknowledged. The cross-sectional design does not allow causal inference or predictive validation, and the reliance on self-reported perceptions may be influenced by contextual or organizational climate effects. Future research should therefore examine predictive and criterion validity, assess longitudinal sensitivity to organizational change, and test cross-cultural measurement invariance. Combining the GEQ with objective ergonomic assessments, observational data, or sustainability performance indicators would also help clarify how perceived organizational readiness relates to actual organizational transformation outcomes.

Overall, the GEQ provides a theoretically grounded and empirically supported tool for investigating employees' perceptions of organizational readiness for green ergonomics. By linking sustainability objectives with work-system design, organizational processes, and participatory dynamics, the questionnaire contributes to ongoing research on sustainable work transformation and offers a structured basis for future empirical

and applied studies at the intersection of ergonomics, organizational development, and environmental sustainability.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/su18062785/s1>: Table S1: Full exploratory factor pattern matrix (principal axis factoring, oblimin rotation).

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Appendix A Green Ergonomics Questionnaire (GEQ)

The Green Ergonomics Questionnaire (GEQ) was originally developed and validated in French to assess employees' perceptions of organizational readiness for integrating environmental sustainability into ergonomic practices. The items capture employees' perceptions of organizational conditions, practices, and capabilities that may support the integration of sustainability into ergonomic work systems. The English translation provided here is conceptually equivalent and intended for international research use. The questionnaire includes 32 items across seven dimensions.

All items are rated on a five-point Likert scale ranging from 1 = Strongly disagree to 5 = Strongly agree.

Original language: French–English translation provided for cross-cultural reference.

1. Connaissances/Knowledge

Je comprends comment mon activité professionnelle peut avoir un impact sur l'environnement.

I understand how my professional activity can impact the environment.

Je connais les pratiques ergonomiques permettant de réduire la consommation d'énergie ou de ressources.

I know ergonomic practices that help reduce energy or resource consumption.

Je suis informé(e) des politiques ou démarches environnementales mises en place dans mon organisation.

I am informed about the environmental policies or initiatives implemented in my organization.

Je sais comment adapter mon poste de travail pour réduire son impact environnemental.

I know how to adapt my workstation to reduce its environmental impact.

Je comprends la relation entre bien-être au travail et performance environnementale.

I understand the relationship between well-being at work and environmental performance.

2. Formation et compétences/Training and Skills

J'ai reçu une formation sur les pratiques durables ou éco-responsables au travail.

I have received training on sustainable or eco-responsible practices at work.

Je me sens compétent(e) pour identifier des solutions de travail respectueuses de l'environnement.

I feel competent to identify environmentally friendly work solutions.

Mon organisation propose des formations intégrant la santé, la sécurité et l'environnement.

My organization offers training that integrates health, safety, and environmental aspects.

Les formations internes m'aident à comprendre comment concilier performance et durabilité.

Internal training helps me understand how to reconcile performance and sustainability.

3. Pratiques organisationnelles/Organizational Practices

Je trie et recycle les déchets issus de mon activité professionnelle.

I sort and recycle waste from my professional activity.

Je limite le gaspillage de ressources (papier, énergie, eau) dans mon travail quotidien.

I limit the waste of resources (paper, energy, water) in my daily work.

J'utilise des outils ou équipements conçus pour réduire l'impact environnemental.

I use tools or equipment designed to reduce environmental impact.

Je propose ou participe à des initiatives visant à améliorer la durabilité des pratiques de travail.

I propose or participate in initiatives to improve the sustainability of work practices.

Mon équipe échange régulièrement sur les moyens de rendre le travail plus durable.

My team regularly discusses ways to make work more sustainable.

4. Impacts perçus/Perceived Impacts

Les pratiques durables améliorent la qualité de mon environnement de travail.

Sustainable practices improve the quality of my work environment.

Je pense que les actions environnementales renforcent la cohésion de l'équipe.

I believe environmental actions strengthen team cohesion.

Les démarches écologiques favorisent la motivation et l'implication au travail.

Environmental initiatives promote motivation and engagement at work.

Je constate que les efforts en faveur de la durabilité sont reconnus dans mon organisation.

I notice that efforts toward sustainability are recognized in my organization.

5. Obstacles/Obstacles

Les ressources nécessaires (temps, matériel, soutien) manquent pour mettre en œuvre des pratiques durables.

The necessary resources (time, equipment, support) are lacking to implement sustainable practices.

Les contraintes de production limitent les possibilités d'intégrer la durabilité dans le travail.

Production constraints limit the possibility of integrating sustainability into work.

Les objectifs environnementaux ne sont pas considérés comme prioritaires par la direction.

Environmental objectives are not considered a priority by management.

Les procédures internes rendent difficile la mise en place d'actions écologiques.

Internal procedures make it difficult to implement ecological actions.

6. Culture organisationnelle/Organizational Culture

Mon organisation valorise les comportements respectueux de l'environnement.

My organization values environmentally friendly behavior.

La direction encourage activement les initiatives écologiques.

Management actively encourages ecological initiatives.

Les décisions ergonomiques prennent en compte les impacts environnementaux.

Ergonomic decisions take environmental impacts into account.

La durabilité fait partie intégrante de la stratégie et de la culture de mon organisation.

Sustainability is an integral part of my organization's strategy and culture.

7. Implication des salariés/Employee Involvement

Je participe à des projets visant à réduire l'empreinte environnementale de mon organisation.

I participate in projects aimed at reducing my organization's environmental footprint.

J'échange avec mes collègues sur des pratiques professionnelles plus durables.

I discuss more sustainable professional practices with my colleagues.

Je me sens encouragé(e) à proposer des idées pour améliorer la durabilité au travail.

I feel encouraged to propose ideas to improve sustainability at work.

Je prends personnellement des initiatives pour réduire l'impact environnemental de mon travail.

I personally take initiatives to reduce the environmental impact of my work.

Mon implication dans les actions environnementales est reconnue par mes supérieurs.

My involvement in environmental actions is recognized by my superiors.

Je considère la durabilité comme une responsabilité partagée entre salariés et direction.

I consider sustainability a shared responsibility between employees and management.

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