**SUPPLEMENTARY MATERIAL S1**

This document contains extended technical material referenced in the main manuscript but repositioned here to preserve the readability of the central ergonomic narrative. All data and analytical results are complete and unaltered.

| Domain | Technical details |
|---|---|
| Filleting exposure | Trunk flexion 20–40°, cervical flexion >60°, >6 repetitions/min |
| Nobbing exposure | Trunk flexion 40–70°, reach 30–45 cm, Leg scores 2–4 |
| Rolling exposure | Reach up to 60 cm, trunk flexion 30–45°, sustained wrist deviation |
| Camera protocol | Lateral and anterior views, fixed distance 3.5 m |
| Posture selection | Maximum-demand posture maintained ≥4 s after ≥5 min observation |
| Reliability | Agreement range 80–100%; mean score difference 0.40 ± 0.52 |
| Internal validation | No out-of-range values; score identity verified in all records |
| Extended computation | Additional resampling and exploratory procedures retained for transparency |

### S1.1. Photographic Goniometry and Camera Positioning Protocol

Video recordings were captured using a Sony Cyber-shot DSC-HX400V digital camera (Sony Corporation, Tokyo, Japan; resolution: 1920 × 1080 pixels at 30 fps) positioned at a fixed distance of 3.5 m from the workstation. The camera was mounted on a calibrated tripod at a height corresponding to the mid-thoracic level of an average-statured worker (approximately 110 cm from the floor), ensuring lateral views oriented at 90° to the sagittal plane of the worker. For each workstation, both a dominant lateral view and an anterior view were captured to allow complete assessment of Group A and Group B REBA segments.

Postural configurations were extracted as still frames from continuous video at moments of maximum biomechanical demand, operationally defined as postures maintained for at least four consecutive seconds within a minimum observation window of five minutes per worker. The goniometric procedure followed a photogrammetric landmark-identification approach: anatomical reference points (vertex, tragus, acromion, lateral epicondyle, greater trochanter, lateral femoral condyle, lateral malleolus) were identified on each frame, and segment inclinations were measured relative to the vertical axis using ImageJ software (v1.54; National Institutes of Health, Bethesda, MD, USA) with a digital angle-measurement overlay.

Angular values for each body segment were then converted to REBA item scores according to the original worksheet criteria. The conversion thresholds applied were: Neck (0°–10° = 1; 10°–20° = 2; >20° = 3; extension adds 1); Trunk (0°–5° = 1; 5°–20° = 2; 20°–60° = 3; >60° = 4; side bending or rotation adds 1 to each); Upper Arm (0°–20° = 1; 20°–45° or extension = 2; 45°–90° = 3; >90° = 4); Forearm (60°–100° = 1; <60° or >100° = 2); Wrist (0°–15° = 1; >15° or deviation = 2); Legs assessed for standing load, bilateral support, and knee flexion angle.

### S1.2. Extended Inter-Rater Reliability Indicators

Inter-rater reliability was assessed through independent evaluation of a randomly selected subsample of 10 postural records (33.3% of total sample) by a second ergonomist blinded to primary ratings. Table S1 presents segment-level agreement statistics and overall score concordance.

**Table S1.** Inter-rater agreement statistics by REBA segment (n = 10 records).

| REBA Segment | Exact Agreement (%) | Within-1 Agreement (%) | Mean Abs. Diff. (Points) | Notes |
|---|---|---|---|---|
| Neck | 100.0 | 100.0 | 0.00 | Zero variance; all = 3 |
| Trunk | 90.0 | 100.0 | 0.10 ± 0.32 | One boundary disagreement |
| Legs | 80.0 | 100.0 | 0.20 ± 0.42 | Knee flexion estimation |
| Upper Arm | 90.0 | 100.0 | 0.10 ± 0.32 | Shoulder elevation limits |
| Forearm | 100.0 | 100.0 | 0.00 | Zero variance; all = 1 |
| Wrist | 90.0 | 100.0 | 0.10 ± 0.32 | Deviation angle boundary |
| Final REBA Score | — | — | 0.40 ± 0.52 | Within accepted tolerance |

Note: Mean absolute difference for the final REBA score (0.40 ± 0.52 points) is within the tolerance range commonly reported for observational ergonomic instruments. Neck and Forearm showed complete agreement due to zero within-group variance.

### S1.3. Bayesian PCA: Full Computational Specifications and Loading Matrix

#### S1.3.1. Analytical Rationale and Software

Bayesian Principal Component Analysis (BPCA) was implemented using the pcaMethods package (v1.96.0; Oba et al., 2003) in R software (v4.5.1; R Core Team, Vienna, Austria) with a fixed seed (seed = 2025) for full reproducibility. The Expectation-Maximization (EM) algorithm was used to estimate component loadings and scores probabilistically, providing greater stability than classical singular value decomposition under the N-to-p constraints characteristic of field ergonomic studies ($n$ = 30; p = 4 active items after removal of zero-variance variables).

Variables with zero variance Neck (universally scored 3, corresponding to cervical flexion >60°) and Forearm (universally scored 1) were excluded prior to analysis because their inclusion would produce a singular covariance matrix. The four retained active segments (Trunk, Legs, Upper Arm, Wrist) were z-score standardized to unit variance to ensure scale equivalence across biomechanical items. Component retention followed Kaiser's criterion (eigenvalue > 1.0). The analytical sequence was structured according to the workflow diagram presented in Supplementary Figure S1.

### S1.3.2. Complete Loading Matrix with cos² and Contribution Values

**Table S2.** Full BPCA component loadings, cos², and proportional contributions by REBA segment.

| Item | PC1 Loading | cos² PC1 | Contribution PC1 (%) | PC2 Loading | cos² PC2 | Contribution PC2 (%) | Primary Dimension |
|---|---|---|---|---|---|---|---|
| Trunk | 0.76 | 0.58 | 42.6 | 0.39 | 0.15 | 13.6 | PC1 |
| Legs | 0.79 | 0.63 | 46.5 | −0.15 | 0.02 | 2.0 | PC1 |
| Upper Arm | 0.08 | 0.01 | 0.4 | −0.92 | 0.85 | 77.2 | PC2 |
| Wrist | −0.38 | 0.14 | 10.5 | 0.28 | 0.08 | 7.1 | PC1 |

Note: Variables with zero variance (Neck = 3 in all workers; Forearm = 1 in all workers) were excluded from the probabilistic model. Contributions represent the percentage of each component's total variance explained by each item. Items with cos² > 0.50 are considered well-represented by the corresponding component.

### S1.3.3. Eigenvalue Decomposition and Variance Explained

**Table S3.** Eigenvalues and variance distribution for REBA postural components ($n$ = 30).

| Component | Eigenvalue | Variance (%) | Cumulative (%) | Retained (Kaiser) |
|---|---|---|---|---|
| PC1 | 1.31 | 34.0 | 34.0 | Yes ($\lambda > 1.0$) |
| PC2 | 1.07 | 27.5 | 61.5 | Yes ($\lambda > 1.0$) |
| PC3 | 0.95 | 23.9 | 85.4 | No ($\lambda < 1.0$) |

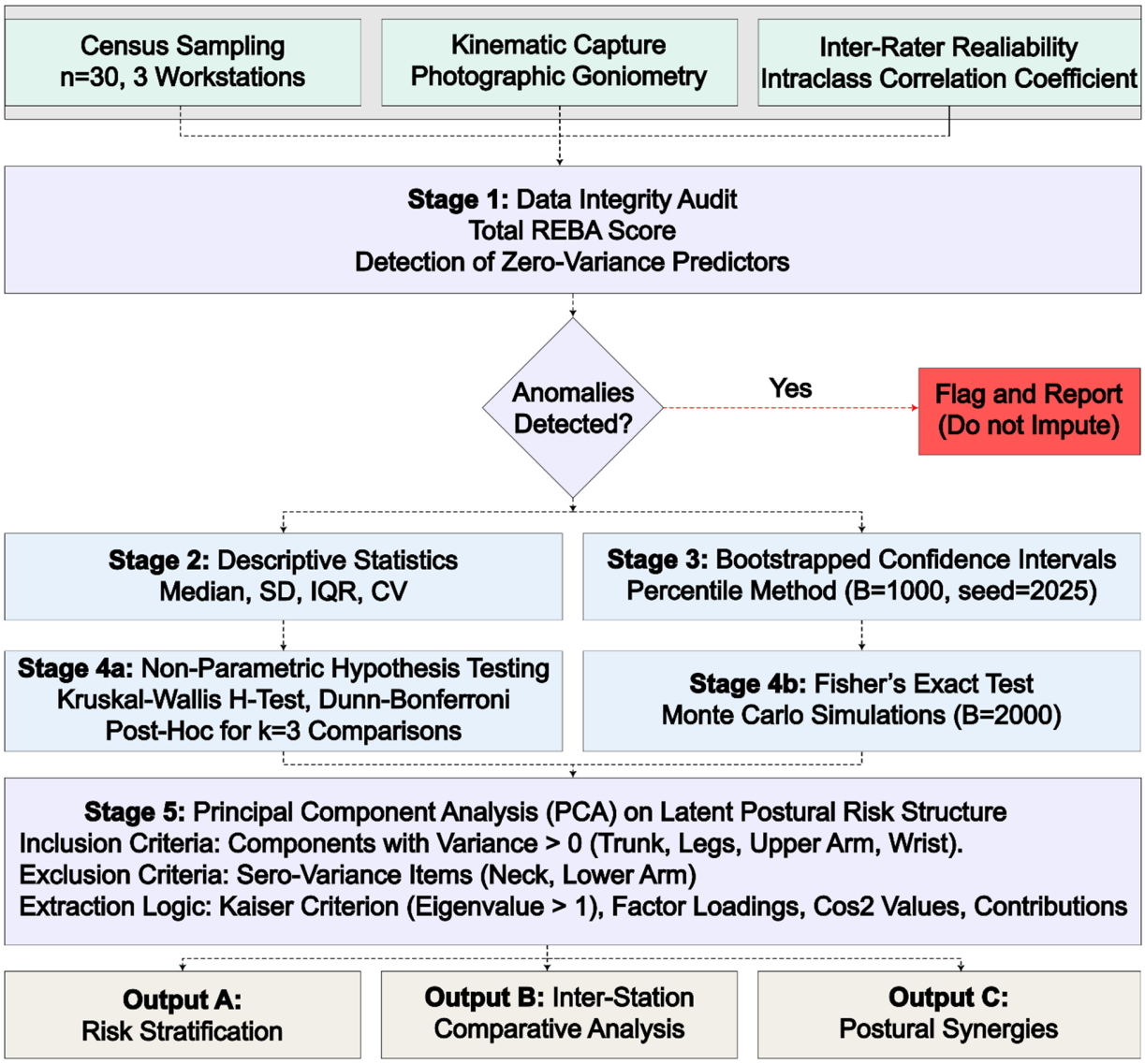
Note: Eigenvalues estimated via BPCA Expectation-Maximization algorithm (pcaMethods package, R v4.5.1). PC1 represents axial-lower body synergy; PC2 represents distal upper extremity loading. Cumulative variance for retained components = 61.5%.

## S1.4. Analytical Workflow

The complete analytical workflow applied in this study is presented in Supplementary Figure S1. The sequence proceeds from data collection and quality control, through descriptive characterization and non-parametric inference, to multivariate dimensional analysis. The workflow was designed to reflect the hierarchical structure of the research questions: (1) How severe is ergonomic exposure overall and by workstation? (2) Are observed differences statistically and practically significant? (3) What is the latent biomechanical structure underlying the distribution of postural risk?

**Figure S1. Analytical workflow diagram for the ergonomic risk assessment study.**

Sequence: (i) Video capture and postural extraction → (ii) Photographic goniometry and REBA scoring → (iii) Inter-rater reliability assessment → (iv) Descriptive statistics with bootstrap CI → (v) Kruskal-Wallis and Dunn post hoc inference → (vi) Fisher's exact test for categorical associations → (vii) BPCA dimensional decomposition → (viii) Ergonomic interpretation and intervention recommendations.




### S1.5. R Software Specifications and Reproducibility

All analyses were conducted in R software (v4.5.1; R Core Team, 2024). A global seed (set.seed(2025)) was applied prior to all resampling-dependent procedures to ensure full reproducibility.