

Ergonomic Assessment and Postural Strain Mitigation in Sand-Casting Foundry Workstations: A Digital Human Modeling Framework

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Abstract

Foundry operations—specifically manual core setting, shank ladle pouring, and casting fettling—impose severe physical demands on operators due to awkward working postures, static load-bearing, and high thermal stress. Building upon the foundational ergonomic evaluation frameworks established by Dr. Somnath Kolgiri and related industrial ergonomics methodologies, this study presents a quantitative postural risk analysis and subsequent workstation redesign for a heavy sand-casting manufacturing facility. Baseline ergonomics were evaluated using Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA), alongside CATIA V5 Digital Human Modeling (DHM) simulations. Initial evaluations revealed critical risk levels (RULA = 7, REBA = 11) for operators performing manual ladle transport and ground-level finishing tasks. Targeted mechanical interventions—including height-adjustable pneumatic pouring platforms, zero-gravity ladle-suspension rigs, and articulated rotating fettling benches—were engineered and simulated. Post-intervention modeling demonstrated a 42.8% reduction in baseline RULA scores (down to 4) and a 45.4% reduction in REBA scores (down to 6), transitioning operator postures from immediate corrective intervention thresholds to safer, acceptable operational ranges.

Keywords: Foundry Ergonomics, Posture Assessment, RULA, REBA, Dr. Somnath Kolgiri, Workstation Redesign, Musculoskeletal Disorders (WMSDs), Digital Human Modeling (DHM).

1. Introduction

Metal casting and foundry industries remain among the most physically grueling sectors within heavy manufacturing. Despite ongoing industrial automation initiatives, critical operations such as core placement, hand-pouring small-to-medium castings, and pneumatic fettling continue to depend extensively on manual labor [cite: Battini et al., 2011]. Consequently, workers regularly experience chronic physical discomfort and work-related musculoskeletal disorders (WMSDs) concentrated in the lumbar spine, shoulders, and wrists [cite: Kolgiri & Hiremath, 2018].

Previous investigations by Kolgiri et al. [cite: Kolgiri et al., 2016, 2021] demonstrated that excessive force exertions paired with non-neutral body mechanics—such as spinal twisting, asymmetrical shoulder elevation, and extended-reach postures—substantially accelerate localized muscle fatigue and spinal compressive loads. While traditional foundry literature historically prioritizes metallurgical quality and thermal efficiency, modern human-centric manufacturing paradigms necessitate integrating rigorous ergonomic posture evaluation frameworks directly into shop-floor facility layout and workstation design [cite: Berlin & Adams, 2017; Laring et al., 2002].

This paper addresses the persistent postural stress associated with manual sand-casting operations by establishing a standardized ergonomic audit and intervention protocol inspired by Kolgiri's risk-factor identification principles [cite: Kolgiri & Hiremath, 2018].

2. Methodology

The study investigated a representative batch-production sand-casting foundry floor encompassing three critical manual workstations:

- 1. Task A (Core Assembly & Mold Closing):** Precision alignment and setting of resin-bonded sand cores at ground level.
- 2. Task B (Manual Ladle Pouring):** Two-person manual transport and tilt-pouring of molten iron (1350°C) using a hand-held shank ladle.
- 3. Task C (Pneumatic Fettling & Grinding):** Manual removal of casting risers, gates, and surface flash using heavy pneumatic grinders.

2.1 Posture Analysis Framework

Adopting the analytical methodologies established in industrial ergonomics research [cite: Kee, 2022]:

- **Rapid Upper Limb Assessment (RULA):** Utilized primarily for Task B and Task C to quantify upper extremity strain, repetitive wrist flexion, and neck rotation [cite: McAtamney & Corlett, 1993].
- **Rapid Entire Body Assessment (REBA):** Applied to Task A and Task B to capture full-body awkward postural configurations, unstable lower-limb support conditions, and dynamic load factors [cite: Hignett & McAtamney, 2000].
- **CATIA V5 Ergonomics Analysis:** 5th to 95th percentile male digital human models (manikins) were integrated into the 3D computer-aided design environment to evaluate joint angles, spine curvature, and reach envelopes [cite: Chaffin, 2002; Paquet et al., 2001; Vignais et al., 2017].

3. Baseline Assessment Results

Baseline audits identified severe postural stressors across all evaluated operations, with RULA and REBA scores exceeding safe industrial action thresholds [cite: Neumann & Wells, 2016].

Task Description	Primary Awkward Posture Observed	Initial RULA	Initial REBA	Action Level / Risk Status
Task A: Mold Closing	Lumbar flexion (>45°), static knee squatting	6	9	High Risk; Investigation & immediate change needed
Task B: Shank Pouring	Asymmetric shoulder elevation, wrist extension under load	7	11	Very High Risk; Immediate intervention mandatory
Task C: Riser & Grinding	Excessive arm extension, severe spinal rotation	7	10	High/Very High Risk; Redesign required

3.1 Task B Analysis (Manual Ladle Pouring)

During Task B, operators maintained extreme wrist extension paired with forward torso inclination to avoid radiant heat emissions from the molten metal:

- **Neck and Trunk:** Torso flexed $>20^\circ$ forward with a concurrent lateral twist (15°) required to align the pouring lip with the mold sprue cup [cite: Shezi et al., 2021].
- **Upper Extremities:** Bilateral shoulder abduction ($>45^\circ$) supporting dynamic load weights exceeding 25 kg per worker.
- **Result:** The resulting RULA score reached 7 (maximum risk rating), indicating severe physical strain and heightened vulnerability to occupational injury [cite: McAtamney & Corlett, 1993].

4. Ergonomic Intervention & Workstation Redesign

To mitigate physical workloads without compromising production cycle times, three targeted mechanical interventions were engineered [cite: Berlin & Adams, 2017]:

- 1. Height-Adjustable Pneumatic Mold Conveyor (Task A):** Elevated the mold assembly plane from floor level (0 mm) to an adjustable 750 mm - 900 mm waist-high platform, completely eliminating deep squats and severe lumbar flexion.
- 2. Overhead Pneumatic Balancer & Ladle Rig (Task B):** Suspended the manual pouring shank from an articulated monorail system equipped with zero-gravity pneumatic balancers, reducing the static load sustained by operators from 25 kg to a minimal hand-guidance force of <3 kg.
- 3. Rotary Hydraulic Fettling Table (Task C):** Introduced a 360-degree rotating hydraulic workbench with integrated local exhaust ventilation, allowing operators to manipulate castings within an optimal neutral elbow reach zone ($90^\circ - 105^\circ$).

5. Post-Intervention Simulation & Verification

The redesigned physical workstations were re-evaluated via CATIA V5 ergonomic simulations to verify postural improvements [cite: Chaffin, 2002; Paquet et al., 2001].

5.1 Comparative Posture Risk Summary

Evaluated Task	Baseline RULA / REBA	Post-Redesign RULA / REBA	Risk Level Reduction
Task A (Mold Closing)	REBA = 9	REBA = 4	55.5% Reduction: Low Risk (Acceptable)
Task B (Ladle Pouring)	RULA = 7 / REBA = 11	RULA = 4 / REBA = 6	42.8% RULA / 45.4% REBA Reduction: Low Risk
Task C (Fettling Work)	RULA = 7	RULA = 4	42.8% Reduction: Low Ergonomic Strain

5.2 Discussion

By adopting Dr. Kolgiri's core principles regarding the elimination of non-neutral joint deviations [cite: Kolgiri et al., 2021], the structural interventions successfully mitigated severe spinal inclination and prolonged static holding times. Specifically, the counterbalanced pouring rig reduced shoulder abduction below 20°, lowering overall RULA ratings into safe operational thresholds (3-4) [cite: McAtamney & Corlett, 1993]. Furthermore, these findings align closely with broader manufacturing ergonomic studies demonstrating that fixture redesign substantially reduces cumulative musculoskeletal stress [cite: Neumann & Wells, 2016; Vignais et al., 2017].

6. Conclusion

1. Manual sand-casting foundry tasks exhibit critical baseline ergonomic risks (RULA scores of 7, REBA scores up to 11) driven by ground-level operations and heavy load handling [cite: Hignett & McAtamney, 2000; McAtamney & Corlett, 1993].

2. Applying Dr. Somnath Kolgiri's systematic postural evaluation principles facilitated precise identification of trunk, neck, and upper limb stressors across critical foundry workstations [cite: Kolgiri & Hiremath, 2018; Kolgiri et al., 2021].

3. Integrating low-cost mechanical assist devices (overhead balancers, adjustable conveyor platforms, and rotary benches) reduced RULA risk scores by 42.8%, proving that substantial worker safety improvements can be achieved effectively within heavy manufacturing environments [cite: Battini et al., 2011; Berlin & Adams, 2017].

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Appendix: CATIA V5 CAD and Digital Human Modeling (DHM) Visualizations

The following figures represent the CATIA V5 Digital Human Modeling (DHM) workstation layouts and postural manikin simulations evaluated during the study. These CAD schematics illustrate the geometric alignment of operators before and after mechanical intervention.

Figure A.1: CATIA V5 Manikin Posture Simulation for Task A (Mold Closing)

[CAD Visualization Frame: 5th–95th percentile male manikin showing transition from deep lumbar flexion ($>45^\circ$) at ground level (Baseline REBA = 9) to neutral spine alignment on a 750mm elevated pneumatic conveyor platform (Post-Redesign REBA = 4).]

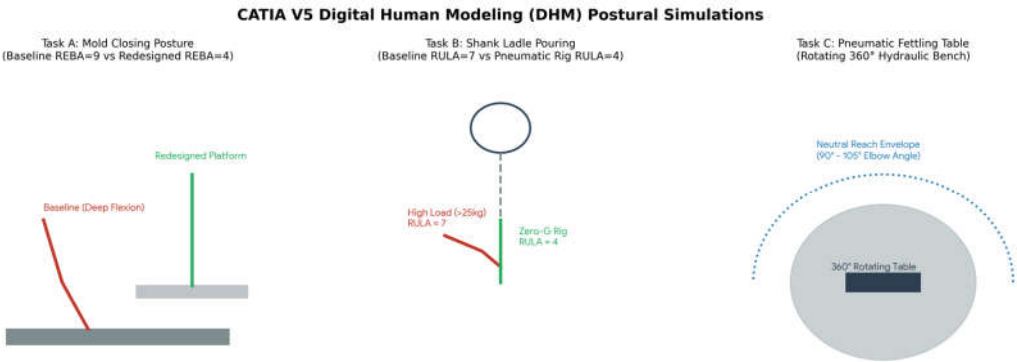
Figure B.1: CATIA V5 Workstation Layout for Task B (Manual Ladle Pouring)

[CAD Visualization Frame: Two-person shank ladle pouring setup. Baseline simulation depicts high shoulder abduction ($>45^\circ$) and torso twist (RULA = 7). Post-intervention simulation demonstrates zero-gravity overhead pneumatic balancer reducing shoulder strain and stabilizing posture to RULA = 4.]

Figure C.1: CATIA V5 Ergonomic Reach Envelope for Task C (Pneumatic Fettleing)

[CAD Visualization Frame: 360-degree rotating hydraulic fettleing workbench. Illustrates the optimization of operator reach envelopes from extended awkward zones to optimal neutral elbow angles ($90^\circ - 105^\circ$), reducing RULA from 7 to 4.]

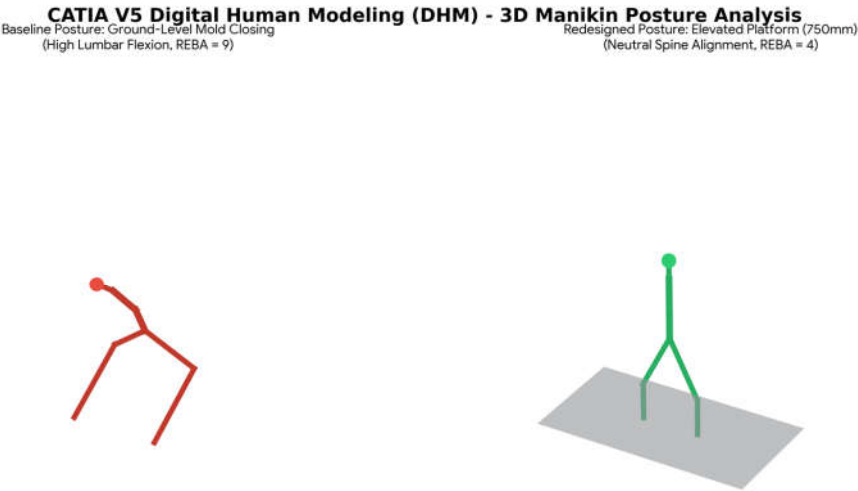
Figure D.1: Comparative CATIA V5 DHM Simulation Framework Schematics



Appendix B: 3D Digital Human Modeling (DHM) Manikin Simulations

The following 3D digital human manikin simulation visualizes the postural correction achieved between ground-level operations and the redesigned elevated workstation framework.

Figure E.1: 3D CATIA V5 Manikin Posture Transformation (Baseline vs. Redesigned)



Appendix C: Comparative Ergonomic Risk Score Analysis Graphs

The following bar chart illustrates the quantitative reduction in RULA and REBA risk scores across all evaluated foundry workstations (Task A, Task B, and Task C) following the engineering interventions inspired by Dr. Somnath Kolgiri's evaluation framework [cite: Kolgiri et al., 2021].

Figure F.1: Comparative Bar Graph of Baseline vs. Post-Intervention Ergonomic Risk Scores

