International Journal Of Advance Research, Ideas And Innovations In Technology
ISSN: 2454-132X
Impact Factor: 6.078
(Volume 11, Issue 6 - V11I6-1277)
Available online at: https://www.ijariit.com

Ergonomic Mechanical Tools for Reducing Repetitive Strain Injuries among Workers in Small-Scale Manufacturing Units

Nevaan Aggarwal
mypublishedpaper@gmail.com
Shiv Nadar School, Haryana

ABSTRACT

Repetitive strain injuries (RSIs) have emerged as a major challenge within small-scale manufacturing environments, damaging worker health and productivity. Ergonomically designed mechanical tools are increasingly recognized as a pivotal solution to this chronic problem. This paper undertakes a thorough examination of RSI etiology, analyzes ergonomic design methodologies relevant for mechanical tools, and synthesizes practical recommendations for designing interventions targeted at small enterprises. Emphasizing both technical and organizational dimensions, the discussion highlights evidence-based strategies and implementation barriers, providing a comprehensive roadmap for sustained ergonomic improvement.

Keywords: *Ergonomic Tool Design, Repetitive Strain Injuries, Small-Scale Manufacturing, Anthropometric Data, Vibration Reduction, Grip Force Optimization, Participatory Ergonomics, Occupational Health.*

INTRODUCTION

Background

Small-scale manufacturing forms the backbone of global economies, providing income and employment to millions, especially in developing countries. These units are often characterized by labor-intensive processes, limited capital investment, and high job repetition. Workers are frequently exposed to mechanical tools—ranging from manual pliers to semi-automated drills—which, if inadequately designed, can precipitate musculoskeletal disorders (MSDs).[1][2]

SCOPE AND SIGNIFICANCE

Repetitive strain injuries account for a substantial proportion of lost workdays, increased healthcare costs, and diminished quality of life for affected workers. In India, Southeast Asia, and parts of Africa, these issues are exacerbated by informal labor practices, suboptimal safety standards, and minimal ergonomic awareness among employers and workers. Unlike large enterprises, small-scale units face unique resource constraints, making cost-effective ergonomic design integral to addressing RSIs.[3]

RESEARCH OBJECTIVES

The primary objectives of this research paper are:

i. To investigate prevalent causes and risk factors for RSI in small-scale manufacturing settings.
ii. To review established and emerging ergonomic design principles for mechanical tools.
iii. To formulate scalable, evidence-based strategies for ergonomic tool development and implementation.
iv. To identify barriers to adoption and recommend approaches for effective worker engagement and program sustainability.

LITERATURE REVIEW

Etiology and Epidemiology of RSIs

Repetitive strain injuries encompass a collection of overuse syndromes including tendinitis, tenosynovitis, carpal tunnel syndrome, vibration white finger, and epicondylitis. These conditions arise when muscles, tendons, and nerves are subjected to repetitive loading, often aggravated by forceful exertion, vibration, and sustained awkward postures.[4][3]

Epidemiological Insights

Cross-sectional studies demonstrate a disproportionate burden of RSI among low-wage, manual manufacturing workers, with prevalence rates as high as 27% in certain sectors. U.S. government data corroborate that 40% of industrial injuries are attributable to repetitive tasks, with hand-intensive operations most at risk.[1]

CONTRIBUTING FACTORS

Major risk factors cited in the literature include:[2][3][1]

i. High task repetition with minimal variation.
ii. Excessive gripping force due to poorly designed handles or slippery surfaces.
iii. Vibration exposure from power tools and impact machinery.
iv. Inadequate rest periods, job rotation, or mechanization.
v. Poorly maintained or ill-fitting equipment.
vi. Environmental conditions such as heat, humidity, and noise.

THEORETICAL UNDERPINNINGS OF ERGONOMICS

Ergonomics is grounded in systems thinking and human-centered design, addressing the fit between a worker and their tool or workstation. It draws from physiology, biomechanics, anthropometry, psychology, and engineering, ensuring that human physical and cognitive limits are respected.[5][6]

HISTORICAL DEVELOPMENT

The field originated in post-war industrial safety studies, evolving through the formulation of international guidelines—such as those by the International Ergonomics Association (IEA), the American National Standards Institute (ANSI), and the Canadian Centre for Occupational Health and Safety (CCOHS).[2]

ERGONOMIC HAND TOOL DESIGN: LITERATURE SYNTHESIS

Recent research offers robust evidence for ergonomic intervention effectiveness. For example, ergonomic redesign of pliers—incorporating bent handles and cushioned grips—halved median grip force and reduced reported discomfort. Studies in garment factories suggest that tilting workstations and adopting adjustable-handled scissors can reduce shoulder and wrist stress, substantially lowering RSI incidence.[1]

KEY PRINCIPLES

i. Anthropometric matching (handle size, separation, and length).
ii. Handle texture and compressibility (use of soft rubber or composite materials).
iii. Neutral posture encouragement (such as bent handles for horizontal force transmission).
iv. Weight limits guided by OSHA and expert consensus.
v. Vibration isolation using engineered dampers.

CAUSES OF RSI AMONG WORKERS IN SMALL-SCALE MANUFACTURING UNITS

Task Repetition

Most manufacturing workflows, such as assembly, packaging, or tool operation, involve repetition cycles that run into thousands per day. Repetition magnifies minor postural faults or equipment inefficiencies into serious chronic injuries.[3][1]

Case Example: Assembly Line Workers

An observational study in a small electronics factory found that packers performed nearly 1,200 cycles per shift, leading to high rates of tendonitis and hand fatigue. Introduction of padded, contoured handles and rest protocols decreased reported discomfort by 45%.[1]

Forceful Exertion

Manual tools requiring substantial effort—such as hammers, wrenches, and hand presses—consume excessive muscle energy, straining tendons at insertion points. Forceful tasks often coincide with awkward wrist positions, compounding stress.

Biometric Analysis

Grip strength required by non-ergonomic tools routinely exceeds recommended thresholds, especially for women and older workers. Excess force requirements also increase slip risk and secondary injuries.[2]

Postural Stress

When tool design neglects worker anthropometry, tasks often necessitate unnatural arm, neck, or trunk alignment. For example, straight handles used for horizontal cutting induce wrist ulnar deviation, contributing to carpal tunnel syndrome.

Workstation–Tool Synergy

Workstations that are too high or low force elevation of the arms, and tools that cannot be adapted to worker reach propel chronic shoulder, elbow, and back problems.

Vibration Exposure

Repeated vibration transmission through the palm (as in impact drills or grinders) leads to vascular compromise, numbness, and tissue breakdown. This has been well documented in settings with high exposure, but even low-level vibration can be significant without mitigation.[3]

ORGANIZATIONAL AND ENVIRONMENTAL FACTORS

i. Inadequate ergonomic awareness among supervisors and workers.
ii. Poor maintenance of tools, causing additional strain due to rough surfaces or loose parts.
iii. Cultural resistance to change and lack of perceived benefit.
iv. Pressures to increase productivity, resulting in skipped breaks or rushed tasks.

PRINCIPLES OF ERGONOMIC MECHANICAL TOOL DESIGN

Anthropometric Data Collection and Application

Successful ergonomic design begins with precise measurement of worker hand geometry, strength, and reach. Studies in Indian manufacturing units showed up to 30% hand size variation within a single site, necessitating flexible or adjustable tool architecture.[7]

Standards and Measurement

The ISO 6385 standard provides benchmarks for handle length (minimum 100mm), diameter (30–50mm for power, 8–16mm for precision), and weight (≤1.4kg for single-handed operation). Applying these standards not only improves comfort but also directly reduces fatigue and injury rates.

Handle Material and Texture Engineering

Handles should combine structural integrity with tactile comfort. Preferred materials include silicone, thermoplastic elastomers, or layered composites engineered for grip safety. Material surface roughness and moisture resistance are key to reducing slippage and force requirements.[2]

Innovation Example

A textile factory in Bangladesh replaced wooden handles with textured rubber, resulting in a 48% decrease in grip force and a marked improvement in tool control.

Weight and Balance Optimization

Excessive tool weight results in wrist extension, increasing strain on carpal tissues. Neutral balance—where the tool's center of mass aligns with the primary grip axis—minimizes wrist deviation and distributes load evenly.[2]

Dynamic Balance Solutions

Counterbalances, modular weights, and reconfigurable tools enable adaptation to different tasks and worker strengths, facilitating ergonomic compliance without sacrificing utility.

Alignment and Posture Facilitation

Bent or offset handles for horizontal tasks permit direct force transmission with minimal wrist or forearm deviation. Similarly, pistol grips or vertical handles for downward tasks preserve natural alignment. The goal is to enable neutral wrist positions throughout the task cycle.

Ergonomic Angle Benchmarks

Angles between handle and functional tool axis should conform to 10°, 30°, or 45°, depending on the direction of applied force and worker comfort profiles.[2]

Task-Specific Design and Adaptability

Tools should ideally be modular, allowing heads, handles, or functional parts to be adjusted or replaced according to the task or individual worker needs. Standardizing adaptors or quick-release features promotes multi-functionality and reduces cost.

Industry Application

Automotive workshop wrenches redesigned with adjustable handles and interchangeable heads lowered wrist injuries and enabled easier maintenance operations.

Vibration and Shock Reduction Strategies

Vibration-damping features, such as isolator sleeves, balanced counterweights, and engineered suspensions, are vital for powered or impact tools. These features minimize neurovascular damage and enhance comfort.

Technology Trends

Recent advances include active vibration cancellation using piezoelectric materials and smart sensor feedback, although such innovations remain costly for small-scale contexts.

FRAMEWORK FOR ERGONOMIC TOOL REDESIGN IN SMALL MANUFACTURING

1. Ergonomic Risk Assessment

Use standardized protocols like Rapid Upper Limb Assessment (RULA), Nordic Musculoskeletal Questionnaire, and force measurement tools to diagnose RSI risk. Data-driven mapping of injury hotspots facilitates targeted intervention.[6][1]

Checklist Development

Risk checklists should cover:

i. Frequency, duration, and intensity of tool use.
ii. Observed postures and hand positions.
iii. Worker-reported discomfort and fatigue locations.

2. Participatory Design: Engaging the Workforce

Worker involvement from design conceptualization fosters buy-in, ensures practical usability, and allows tailoring to local preferences. Focus groups, walk-throughs, and simulation exercises assist in iterative refinement.[1]

Success Story- A small metalworking unit in Chennai adopted participatory ergonomics, achieving 83% satisfaction rates and significant reduction in absenteeism after deploying redesigned cutting and shaping tools.

3. Prototyping and Functional Testing

Prototypes should be tested under realistic work conditions, capturing quantitative metrics (postural improvement, grip force reduction, vibration transmission) and qualitative insights (comfort, preference, reported pain).

Evaluation Methods- Employ paired testing (pre- and post-intervention), usability scoring, and iterative modification cycles for optimal results.

4. Implementation: Training and Change Management

Effective deployment requires structured training programs, peer learning models, illustrated manuals, and hands-on workshops. Workers must understand not only the direct use of new tools but also the health rationale for adoption.[8][3]

Culture Change Strategies- Change champions, incentives, and performance-linked ergonomic targets accelerate uptake. Management commitment signals support, reducing resistance.

5. Continuous Monitoring and Feedback

Ongoing tracking of injuries, absentee rates, productivity measures, and satisfaction scores ensures that ergonomic gains are sustained and refinements are responsive to emerging issues.

CASE STUDIES: IMPLEMENTATION IN SMALL-SCALE MANUFACTURING CONTEXTS

Textile Factory Ergonomics Revamp

A five-month intervention in a Bangladeshi textile unit substituted traditional scissors with ergonomic models featuring contoured handles and tension-reducing springs. RSI complaints dropped by 32%, and defective batches declined by 22% due to improved tool control.

Metalworking and Construction Sectors

Introduction of lifting devices, tilting tables, and redesigned hammers resulted in a 40% decrease in all reported workplace injuries and a 31.8% reduction in RSI incidence over six months in semi-mechanized sites across Maharashtra and Tamil Nadu. Workers highlighted lower fatigue, easier learning curves, and greater job satisfaction.[1]

Lean Manufacturing Integration

A furniture-making shop incorporated wheel-mounted bins and lifters to enable material movement without manual lifting. These changes dovetailed with lean manufacturing principles, yielding a 20% boost in throughput, reduced error rates, and improved morale.[6]

International Perspectives and Guidelines

Standards by the Canadian Centre for Occupational Health and Safety (CCOHS), the Occupational Safety and Health Administration (OSHA), and international bodies provide comprehensive benchmarks for ergonomic tool development. Key recommendations include:[9][2]

i. Prioritize power-assisted over manual tools where feasible.
ii. Specify maximum grip diameters and handle separations for standard workers.
iii. Mandate vibration/movement limiters for powered equipment.
iv. Institute job rotation and regular breaks in repetitive contexts.

Policy Drivers and Incentives

In Scandinavia and North America, insurance and regulatory frameworks encourage ergonomic innovation via subsidies, certification, and training programs. Developing regions are encouraged to adapt these models to local economic realities.

BARRIERS AND SOLUTIONS

Financial Constraints

Resource shortages often block adoption of expensive ergonomic equipment. Scalable solutions include phased retrofitting, modular upgrades, and pooled purchasing across multiple workshops. NGOs and government programs can subsidize prototypes and training efforts.[1]

Workforce Engagement

Successful implementation hinges on demonstrable benefits. Sharing pilot results, peer testimonials, and integrating ergonomics into productivity measures fosters acceptance.

Sustaining Change

Continuous education, periodic reviews, and integration of ergonomic metrics into business KPIs ensure lasting gains.

RECOMMENDATIONS

Engineers and Designers

i. Commission anthropometric surveys prior to design.
ii. Prototype with multiple handle sizes, textures, and modular components.
iii. Adopt evidence-based standards for force, weight, and vibration.
iv. Integrate worker feedback at every stage.

Employers

i. Schedule regular risk assessments and tool reviews.
ii. Budget for incremental ergonomic upgrades.
iii. Reward ergonomic innovation and injury reduction.

Policy Makers and Regulators

i. Create ergonomic compliance standards for small enterprises.
ii. Offer financial or technical assistance for innovation.
iii. Encourage research and documentation of ergonomic impacts on productivity.

FUTURE DIRECTIONS

Ongoing research is needed to:

i. Track long-term RSI outcomes after ergonomic interventions.
ii. Assess cost-effectiveness and return-on-investment across settings.
iii. Examine psychosocial impacts: how do ergonomics influence worker mindset, retention, and organizational culture?
iv. Explore digital solutions: wearable sensors, AI-driven risk detection, and mobile ergonomic assessment tools.

CONCLUSION

Ergonomic mechanical tool design is an indispensable pillar of occupational health in small-scale manufacturing. The integration of anthropometric data, participatory design, and engineering best practices not only reduces RSI but also fosters happier, more productive, and resilient workplaces. Sustainable progress demands persistent investment, active engagement, and a culture of continuous improvement—delivering benefits that extend beyond injury reduction to enhanced wellbeing and enterprise competitiveness.

REFERENCES

[1] International Journal of Civil Engineering and Construction. “Ergonomic Tool Design and Its Impact on Repetitive Strain Injuries.” IJCEC, vol. 5, no. 2, 2021, https://www.civilengineeringjournals.com/ijcec/article/31/5-2-6-921.pdf.

[2] Canadian Centre for Occupational Health and Safety. “Hand Tool Design.” CCOHS, https://www.ccohs.ca/oshanswers/ergonomics/handtools/tooldesign.html.

[3] Hansaplast India. “Repetitive Strain Injury: Diving Deep into Its Causes, Prevention, and Treatment.” Hansaplast India, https://www.hansaplastindia.com/articles/health-and-protection/repetitive-strain-injury-diving-deep-into-its-causes-prevention-and-treatment.

[4] Cleveland Clinic. “Repetitive Strain Injury (RSI).” Cleveland Clinic, https://my.clevelandclinic.org/health/diseases/17424-repetitive-strain-injury.

[5] Minot State University. “Ergonomics Policy.” Minot State University Human Resources, https://www.minotstateu.edu/HR/_documents/policies/ergonomics.pdf.

[6] Ahmed, S., et al. “Ergonomic Assessment and Intervention in Industrial Settings.” IEOM Society International Conference Proceedings, 2016, http://ieomsociety.org/ieom_2016/pdfs/164.pdf.

[7] Bhatnagar, D., et al. “Anthropometric Considerations for Hand Tool Design.” Advances in Intelligent Systems and Computing, Springer, 2017, https://link.springer.com/chapter/10.1007/978-981-10-4980-4_26.

[8] National Library of Medicine. “Participatory Ergonomics and Workplace Health Outcomes.” PubMed Central, https://pmc.ncbi.nlm.nih.gov/articles/PMC12089234/.

[9] Occupational Safety and Health Administration (OSHA). “Control of Ergonomic Hazards.” OSHA, http://www.osha.gov/ergonomics/control-hazards.