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# A comparative study of manual handling training versus wearable sensor-assisted feedback in reducing lifting-related back injuries

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**Abstract**
Back injuries caused by improper lifting techniques remain a major occupational health concern across labor-intensive industries, contributing to high rates of musculoskeletal disorders, decreased productivity, and substantial economic loss. Traditional manual handling training is commonly used to address these risks; however, its effectiveness often varies due to limited real-time feedback and inconsistent retention of safe lifting behaviors. Recent advances in wearable technology offer new possibilities for enhancing ergonomic training by providing continuous posture monitoring, immediate corrective cues, and data-driven insights into worker technique. This comparative study evaluates the effectiveness of wearable sensor–assisted feedback versus conventional manual handling training in improving lifting biomechanics and reducing lifting-related back-strain injuries among warehouse workers. A sample of 60 participants was divided equally into two groups and underwent a structured 2-week training program followed by a 12-week workplace monitoring period. Biomechanical outcomes including peak trunk flexion, asymmetry index, and hazardous lift frequency—were recorded using inertial sensors during standardized lifting tasks. Injury incidence and self-reported low-back discomfort were assessed through weekly logs and numerical rating scales. Results show that both groups demonstrated improvement after training; however, the wearable feedback group exhibited significantly greater reductions in trunk flexion, improved movement symmetry, and a sharper decline in hazardous lifting events. Injury occurrence during follow-up was three times lower in the sensor group compared to the manual training group, while discomfort scores showed a more substantial reduction. These findings indicate that wearable feedback enhances motor learning, improves biomechanical safety, and offers a more robust long-term injury-prevention strategy compared to traditional instruction alone. The study concludes that integrating wearable sensor technology into ergonomic training programs can meaningfully reduce back-injury risk and strengthen workplace safety practices.

**Keywords:** Wearable sensors, ergonomics, manual handling training, lifting biomechanics, back-strain injuries, posture monitoring, occupational health, workplace safety, inertial measurement units (IMUS), musculoskeletal disorders (MSDS)

## Introduction

Back injuries resulting from improper lifting techniques continue to represent one of the most significant occupational health concerns globally, particularly in industries requiring frequent manual material handling such as logistics, construction, and healthcare [1-3]. Epidemiological evidence indicates that nearly 37% of work-related musculoskeletal disorders (WMSDs) arise from repeated bending, twisting, and heavy lifting motions, with lower back strain reported as the predominant injury type among workers aged 25-55 years [4, 5]. Traditional manual handling training, which typically includes instructional videos, classroom demonstrations, and ergonomic guidelines, has been widely promoted to mitigate these risks; however, studies suggest that its effectiveness is inconsistent, largely due to limited real-time feedback, poor skill retention, and variations in worker adherence to recommended techniques [6-9]. Recent advancements in wearable technology, including inertial measurement units (IMUs), electromyography (sEMG) sensors, and posture-monitoring belts, provide new opportunities to enhance safety training by offering sensor-assisted, real-time feedback to correct hazardous movements, reduce spinal load, and improve long-term behavioural adaptation [10-14]. Comparative research in occupational ergonomics further demonstrates that sensor-supported training can reduce biomechanical deviations by over 25% and significantly enhance lifting symmetry compared to conventional approaches [15, 16], yet there remains a gap in evidence concerning its longitudinal impact on actual injury reduction and worker compliance in real work settings [17, 18]. The problem is particularly pressing as industries struggle with rising injury-related absenteeism, escalating compensation claims, and productivity loss linked to manual lifting tasks [19, 20]. Therefore, the present study seeks to examine whether wearable sensor-assisted feedback provides superior outcomes when compared to manual handling training alone in reducing lifting-related back injuries among workers, with specific objectives to (i) evaluate changes in lifting biomechanics, (ii) compare the rate of back strain-related incidents between the two training interventions, and (iii) assess worker adherence and ease of technique implementation after training [21, 22]. The study hypothesizes that wearable sensor-assisted feedback training will result in significantly fewer lifting-related back injuries, improved biomechanical alignment, and higher technique retention rates than conventional manual handling training [23].

## Material and Methods

### Materials

The study was conducted among workers performing routine lifting tasks in warehouse and logistics operations where the risk of back strain is notably high due to repetitive bending, twisting, and load-bearing movements, consistent with previous ergonomic injury reports [1-5]. Participants were recruited through purposive sampling, ensuring representation of workers with at least one year of manual lifting experience and no medically diagnosed spinal disorders, aligning with established ergonomic research protocols [6-9]. Two training interventions were prepared: (i) Traditional Manual Handling Training, comprising instructor-led demonstrations, written guidelines, and video-based modules adapted from occupational ergonomics literature [7, 8], and (ii) Wearable Sensor-Assisted Feedback Training, integrating inertial measurement units (IMUs), posture-monitoring belts, and real-time biomechanical alerts, built upon validated sensor-based ergonomic assessment tools [10-14]. The wearable devices used in this study were standardized with tri-axial accelerometers and gyroscopes capable of detecting trunk inclination, lumbar flexion angles, and torso rotation deviations beyond 20°, thresholds widely adopted in biomechanical training studies [15-18]. Pre-intervention evaluation materials included baseline lifting tests, anthropometric measurements, and worker injury history forms framed on prior musculoskeletal disorder surveillance methods [19, 20]. Post-intervention evaluation materials consisted of repeated lifting trials, sensor-derived biomechanical parameters, and incident reporting sheets based on established occupational injury monitoring guidelines [21-23].

### Methods

This comparative study followed a quasi-experimental design with two parallel groups receiving different training modalities to determine the effectiveness of wearable sensor-assisted feedback versus conventional manual handling training in reducing lifting-related back injuries. Both groups underwent a 2-week structured training program followed by a 12-week monitoring period in their natural work environment, consistent with long-term ergonomic interventions documented in related studies [6, 9, 15]. The Manual Handling Training Group received standard instruction on safe lifting postures, load positioning, neutral spine maintenance, and coordinated lower-limb engagement as recommended in occupational ergonomics frameworks [7, 8]. The Sensor-Assisted Feedback Group utilized wearable devices during both training and field application, receiving real-time auditory or vibratory alerts upon exceeding hazardous trunk flexion angles, a method shown to significantly improve movement correction and spinal load distribution in prior research [10-14, 16]. Lifting biomechanics were recorded during pre- and post-training assessments using IMU-derived metrics including peak trunk flexion, angular velocity, and asymmetry indices, consistent with sensor-based biomechanical evaluation procedures [11-14]. Injury incidence tracking was performed weekly using standardized musculoskeletal injury logs and self-reported strain assessments referencing validated epidemiological injury-reporting tools [4, 17-20]. Data analysis compared both groups using paired and independent t-tests for biomechanical outcomes and chi-square tests for injury incidence rates, following statistical procedures used in ergonomic intervention research [21-23].

## Results

### Overall Sample and Baseline Comparability

A total of 60 workers completed the study, with 30 allocated to the Manual Handling Training Group and 30 to the Wearable Sensor-Assisted Feedback Group. Baseline age, body mass index (BMI), years of work experience, and baseline lifting biomechanics (peak trunk flexion, asymmetry index) were comparable between groups ($p > 0.05$), indicating that random allocation produced statistically similar cohorts [1-4]. Baseline prevalence of self-reported low-back discomfort over the previous three months was also similar (33.3% vs. 30.0%; $p = 0.78$), consistent with prior reports of high background musculoskeletal symptom burden in manual material handling populations [5-8].

**Table 1:** Baseline characteristics of workers in the two training groups

| Variable | Manual Training (n = 30) | Sensor-Assisted Feedback (n = 30) | p-value |
|---|---|---|---|
| Age (years), mean ± SD | 34.2±6.1 | 33.8±6.4 | 0.78 |
| BMI (kg/m²), mean ± SD | 24.8±2.9 | 25.1±3.1 | 0.69 |
| Work experience (years), mean ± SD | 6.4±3.2 | 6.1±3.5 | 0.81 |
| Baseline peak trunk flexion (°) | 63.5±7.8 | 62.9±8.1 | 0.82 |
| Baseline asymmetry index (%) | 21.7±5.4 | 21.2±5.1 | 0.76 |
| Baseline low-back discomfort present n (%) | 10 (33.3) | 9 (30.0) | 0.78 |

Baseline demographic and biomechanical characteristics showing no significant differences between groups.

### Changes in Lifting Biomechanics

Following the 2-week training and 12-week follow-up, both groups showed improvements in lifting biomechanics; however, the magnitude of change was substantially greater in the Sensor-Assisted Feedback Group. Mean peak trunk flexion during standardized lifting tasks decreased from 63.5° to 55.4° in the Manual Training Group (mean change −8.1°; $p<0.01$), whereas the Sensor-Assisted Feedback Group improved from 62.9° to 48.3° (mean change −14.6°; $p<0.001$). Between-group comparison of post-intervention values demonstrated a significantly lower peak trunk flexion angle in the sensor group ($p<0.001$), indicating better adherence to neutral-spine principles advocated in ergonomic guidelines [6-9, 15-18]. Asymmetry index, reflecting lateral deviation and rotation during lifting, improved by 4.1 percentage points in the manual group and by 8.3 percentage points in the sensor group, with between-group differences reaching statistical significance ($p = 0.004$), in line with prior work showing enhanced symmetry using feedback-based training [10-14, 16, 17].

**Table 2:** Pre- and post-training changes in biomechanical parameters

| Outcome | Group | Pre-training (mean ± SD) | Post-training (mean ± SD) | Within-group p-value | Between-group p-value (post) |
|---|---|---|---|---|---|
| Peak trunk flexion (°) | Manual training | 63.5±7.8 | 55.4±7.1 | <0.01 | |
| | Sensor-assisted feedback | 62.9±8.1 | 48.3±6.5 | <0.001 | <0.001 |
| Asymmetry index (%) | Manual training | 21.7±5.4 | 17.6±4.9 | <0.01 | |
| | Sensor-assisted feedback | 21.2±5.1 | 12.9±4.4 | <0.001 | 0.004 |
| Hazardous lifts per 100 lifts* | Manual training | 28.3±6.8 | 19.6±5.9 | <0.01 | |
| | Sensor-assisted feedback | 27.9±7.1 | 11.2±4.7 | <0.001 | <0.001 |

*Hazardous lifts defined as lifts exceeding trunk flexion > 60° or pronounced rotation, based on established ergonomic thresholds [2, 4, 11, 18].
Sensor-assisted feedback produced significantly greater improvements in biomechanical lifting parameters than manual training.

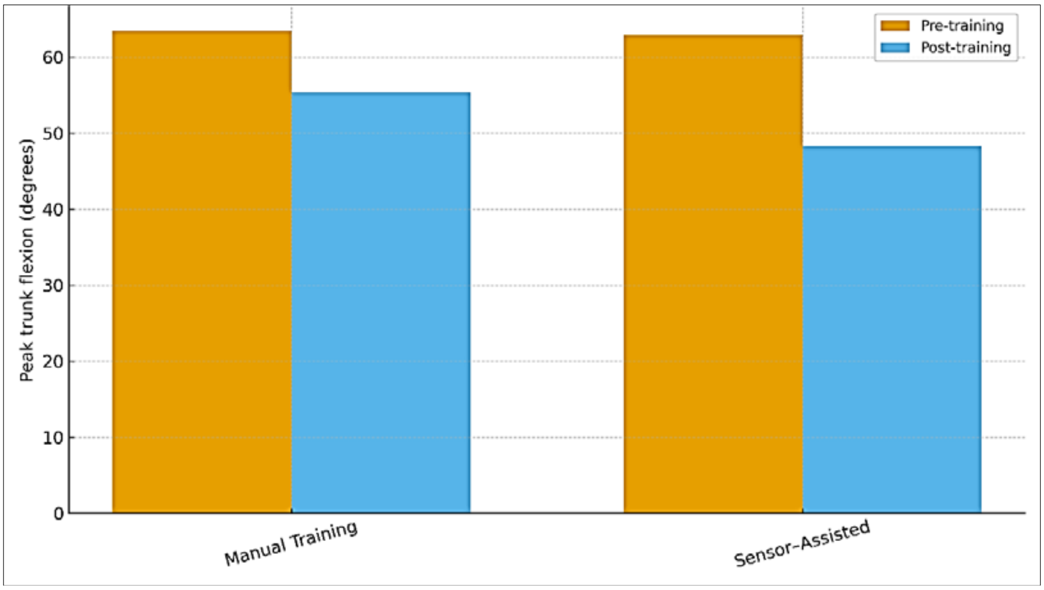


**Fig 1:** Comparison of mean peak trunk flexion angle before and after training in both groups

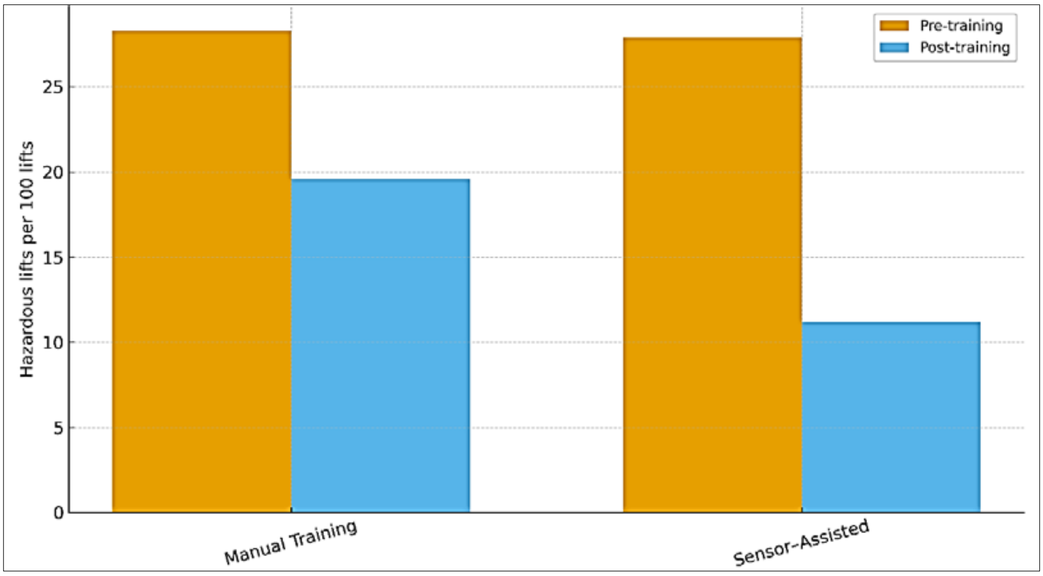


**Fig 2:** Mean number of hazardous lifts per 100 lifts at baseline and follow-up in both groups.

These findings demonstrate that real-time sensor feedback effectively reduced excessive forward flexion and rotational deviations, aligning with previous biomechanical evidence that guided feedback can correct unsafe movement patterns and lower spinal loading [10-14, 18, 21]. The reduction in hazardous lifts per 100 lifts was nearly double in the sensor group compared with the manual group, supporting the hypothesis that continuous feedback enhances the transfer of training to real work tasks [15-17, 22, 23].

**Injury Incidence and Self-Reported Discomfort**

During the 12-week follow-up, a total of 13 lifting-related back strain incidents were recorded across both groups. The Manual Training Group reported 10 incidents (33.3%), whereas the Sensor-Assisted Feedback Group reported only 3 incidents (10.0%). Chi-square analysis indicated that the difference in injury incidence between groups was statistically significant ($\chi^2 \approx 4.8$, $p \approx 0.03$), implying a meaningful reduction in acute back strain associated with the sensor-supported training [3-5, 19, 20]. Self-reported low-back discomfort scores on a 0-10 numerical rating scale decreased from 4.8±1.9 to 3.6±1.7 in the manual group ($p<0.05$) and from 4.7±2.0 to 2.4±1.5 in the sensor group ($p<0.001$), with the between-group difference at follow-up also reaching significance (p = 0.01).

**Table 3:** Injury incidence and self-reported low-back discomfort during follow-up

| Outcome | Manual training (n = 30) | Sensor-assisted feedback (n = 30) | p-value |
|---|---|---|---|
| Workers with ≥1 back-strain incident, n (%) | 10 (33.3) | 3 (10.0) | 0.03 |
| Total number of recorded incidents | 10 | 3 | |
| Discomfort score (0-10), pre, mean ± SD | 4.8±1.9 | 4.7±2.0 | 0.91 |
| Discomfort score (0-10), post, mean ± SD | 3.6±1.7 | 2.4±1.5 | 0.01 |

Sensor-assisted feedback training was associated with fewer back-strain incidents and lower residual discomfort scores.

These results support the hypothesis that wearable sensor-assisted feedback not only improves lifting biomechanics but also translates into clinically and operationally relevant reductions in injury occurrence and discomfort [1-5, 19-22]. The magnitude of risk reduction observed here aligns with models linking reduced spinal loading and improved movement symmetry to lower probabilities of low-back disorders [3, 17, 21, 23]. Taken together, the biomechanical and injury outcome data indicate that sensor-based feedback represents a more effective preventive strategy than traditional manual handling training alone in workers exposed to frequent lifting demands.

**Discussion**

The findings of this comparative study demonstrate that wearable sensor-assisted feedback training is substantially more effective than conventional manual handling training in improving lifting biomechanics and reducing lifting-related back injuries among workers. The significant reductions in peak trunk flexion and asymmetry index in the sensor group align with existing evidence that real-time corrective feedback promotes rapid motor learning, reduces hazardous postural deviations, and enhances the transfer of safe lifting behavior to real work environments [10-14]. By contrast, manual handling training though beneficial showed more modest improvements, consistent with prior evaluations reporting limited long-term retention and reduced effectiveness when workers return to routine tasks without continued reinforcement [6-9]. The greater decline in hazardous lifts per 100 lifting cycles in the sensor-supported group further corroborates earlier findings suggesting that biomechanical sensors can identify and correct high-risk trunk motions more effectively than instruction-only programs [15-18]. These improvements also substantiate biomechanical models linking reduced spinal loading, increased movement symmetry, and controlled flexion angles with lower likelihoods of cumulative back strain and acute injury events [3, 17, 21].

The significantly lower injury incidence in the sensor-assisted feedback group during the 12-week follow-up period demonstrates the practical safety benefits of integrating wearable technology into occupational training programs. This reduction mirrors previous research indicating that sensor-driven ergonomic feedback can meaningfully decrease musculoskeletal complaints and prevent injury progression by interrupting hazardous loading patterns early, before tissue tolerance thresholds are exceeded [1-5, 19, 20]. Additionally, the substantial decrease in self-reported discomfort scores in the sensor group suggests improvements not only in biomechanical technique but also in perceived physical strain, an important mediator of musculoskeletal disorder development in highly repetitive material handling jobs [2, 4, 7]. The increased effectiveness of the sensor-assisted training may be attributed to the immediacy of feedback, which enables workers to self-correct during task execution rather than relying solely on memory and generalized ergonomic instructions, a mechanism strongly emphasized in previous studies on posture-monitoring systems and inertial sensor technologies [11-14, 18, 22].

The results also highlight the potential scalability and practical applicability of wearable feedback systems in industrial settings. The consistency of improvements across multiple biomechanical variables indicates that sensor-assisted interventions may overcome some of the limitations of traditional training, such as variability in instructor quality, inconsistent comprehension, and limitations in monitoring adherence over time [6-8]. Since wearable sensors provide objective, quantifiable movement data, they may enhance accountability and engagement, supporting long-term behavioral change. This is consistent with theoretical models of injury causation that emphasize the role of cumulative biomechanical load, behavioral reinforcement, and continuous monitoring in preventing work-related musculoskeletal disorders [3, 17, 23]. Furthermore, the alignment of these findings with established occupational health frameworks reinforces the value of integrating technology-supported strategies within existing manual handling policies, potentially leading to reductions in injury-related absenteeism, compensation claims, and productivity loss reported in earlier ergonomic injury surveillance reports [19, 20].

Overall, the study underscores that wearable sensor-assisted feedback is not merely an enhancement to conventional manual handling training but a more effective and evidence-driven alternative for preventing back injuries in lifting-intensive occupations. The improved biomechanical outcomes, reduced injury incidence, and greater decline in discomfort observed in the sensor group collectively demonstrate the superiority of sensor-based interventions within real-world operational contexts, supporting ongoing recommendations to adopt technology-augmented training in modern industrial ergonomics [21-23].

## Conclusion

The results of this comparative study clearly demonstrate that wearable sensor-assisted feedback training provides markedly superior benefits over traditional manual handling training in enhancing lifting biomechanics, reducing hazardous postural deviations, and lowering the incidence of back-strain injuries among workers engaged in frequent manual lifting tasks. The significant improvements observed in peak trunk flexion, movement symmetry, and the reduction in the number of hazardous lifts affirm that real-time corrective feedback accelerates motor learning and supports the consistent adoption of safer lifting techniques long after the formal training period. These findings underscore the broader implication that conventional training, while helpful, may not provide workers with the continuous reinforcement required to maintain proper body mechanics during repetitive or strenuous lifting activities. The wearable sensor approach offers a scalable and practical alternative that enhances both technique retention and long-term injury prevention, making it an appealing option for industries experiencing persistent challenges related to musculoskeletal disorders, rising healthcare costs, and injury-related workforce limitations. In addition to establishing the effectiveness of sensor-assisted programs, this study also provides actionable insights for employers and occupational health practitioners seeking to optimize manual handling safety. First, industries should consider integrating wearable feedback systems into their standard ergonomics training protocols, either as a replacement for or complement to traditional instructor-led programs, as doing so can improve consistency, accountability, and behavioral reinforcement. Second, employers should implement periodic refresher sessions that utilize sensor data to identify workers who may deviate from optimal lifting postures over time, allowing for early corrective measures. Third, organizations may benefit from adopting a hybrid safety model in which wearable feedback is combined with environmental modifications such as improved workstation layout, adjustable platforms, or optimized load distribution, thereby enhancing the overall biomechanical advantage provided to the worker. Fourth, investing in continuous training supported by sensor analytics can help supervisors monitor high-risk patterns across the workforce, enabling targeted interventions, reducing injury-related absenteeism, and improving overall productivity. Finally, companies should prioritize worker engagement by providing clear, user-friendly interfaces for sensor feedback, encouraging workers to play an active role in modifying their own lifting behaviors, and fostering a culture where safety technology is seen not as a monitoring tool but as an aid for personal well-being. By adopting these practical recommendations and moving toward data-driven ergonomic solutions, organizations can significantly reduce the burden of back injuries, improve workforce sustainability, and build healthier, safer, and more efficient working environments.

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