Ergonomic Analysis of Warehouse Work Using Scalefit

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Warehouse work often involves frequent handling, awkward postures, and repetitive actions that can raise long-term risk for back, neck, and shoulder pain. This matters more in a longevity society, where firms need safe work design that supports work ability across the whole workforce. This paper presents a practical workflow that links wearable full-body motion capture (Xsens) with Scalefit reports to assess physical load in real warehouse conditions. We record a worker during normal work and split the recording into work blocks that match how the job actually runs. The system then produces Excel-based outputs that summarize posture and movement over time, highlight peak-load moments, and flag body regions with higher strain. We use the outputs to rank work blocks by risk, compare work done with different load demands, and point to changes that an employer can act on (layout, shelf height, load limits, tools, and work rotation). The main contribution is a repeatable, on-site method that turns sensor data into clear ergonomics findings that support safer work design and longer working lives.

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1   Introduction

Musculoskeletal disorders (MSDs) are prevalent in occupations involving manual and repetitive material handling (Balantič et al., 2016). In warehouse work, it is no different – repetitive lifting, carrying, and awkward postures are well-known risk factors for injuries to the lower back, shoulders, and other body regions (Barim & Lu, 2020; Zhao et al., 2022). Effective ergonomic risk assessment is therefore critical to improve worker safety and reduce injury rates. Traditional assessment methods – for example, observational tools and checklists like OWAS, RULA, or REBA – provide qualitative or categorical evaluations of posture and load, but they often rely on expert observation and can be subjective or time-consuming (Rybnikár et al., 2022; Medved et al., 2025).

Recent advances in wearable sensor technology offer a means to augment or, in some cases, replace these traditional methods with more objective, data-driven analyses (Lind et al., 2023). In particular, inertial measurement unit (IMU)-based motion capture systems allow continuous 3D tracking of a worker's body segment positions and joint angles throughout actual work tasks (Simon et al., 2024). Such systems can vastly improve the precision of exposure measurements compared to manual observation, capturing dynamic movements and peak exertions that might be missed or underestimated by human assessors. Moreover, new sensor fusion and machine learning approaches are improving automated scoring accuracy and reducing analyst workload (Krishnan et al., 2024). Research has also shown that wearable motion capture provides superior accuracy in measuring trunk and limb postures and enables real-time and automated ergonomic analysis (Humadi et al., 2021; Lind et al., 2023).

This paper explores the use of a wearable motion capture system paired with specialized ergonomic analysis software to evaluate the physical stresses of warehouse work. The Scalefit Industrial Athlete system – a biomechanical assessment tool integrating IMU sensors, biomechanical modeling, and ergonomic evaluation metrics – was used in this study. The system adheres to relevant ergonomic standards (e.g., DIN and ISO guidelines) to evaluate postures, movements, and physical loads in real time (Lind et al., 2023; Simon et al., 2024). It computes objective risk indicators such as joint angle excursions, velocities, and estimated spinal loads, and summarizes these in an ergonomic risk score

accompanied by a color-coded risk classification (from low to high risk). By analyzing several distinct warehouse tasks, we aim to (1) identify peak-risk patterns in each task, (2) compare the overall task demands and risk levels, and (3) demonstrate how the quantitative outputs from the motion capture analysis support ergonomic decision-making. The goal is to illustrate how data-driven insights can guide interventions – whether through redesigning tasks and workstations or providing targeted training – to mitigate the highest risks in warehouse jobs.

2   Methodology

This study is a single-subject pilot conducted to test a practical workflow for field ergonomic assessment. One healthy adult female warehouse worker performed four representative tasks: (1) placing and retrieving a 16 kg box on and from a mid-level shelf, (2) retrieving a lightweight box from a high shelf with and without a ladder, (3) lightweight box packing, and (4) carrying a 10 kg box downstairs (from 3rd to 1st floor). The worker (Figure 1) performed tasks in a realistic manner to capture typical postures and peak-load moments.
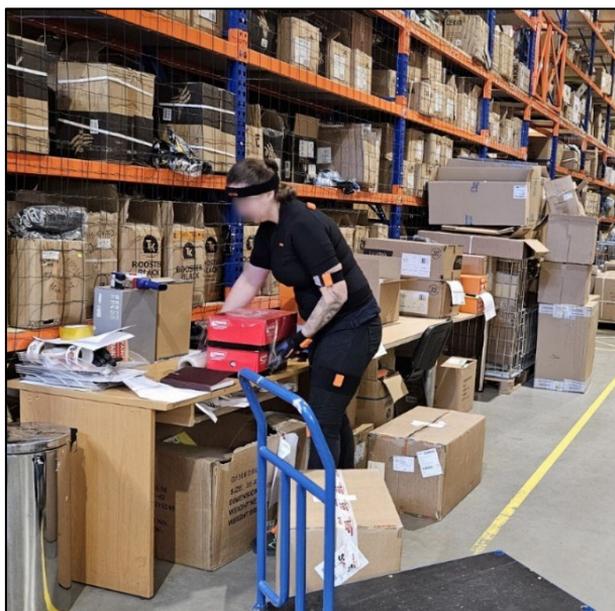

Figure 1: Warehouse worker packing a box
Source: Own

Full-body kinematics were recorded using an IMU-based motion capture suit (Xsens). Motion data were processed in Scalefit, which applies a scaled biomechanical model and known external loads (object masses entered as 16 kg, 10 kg, and 2 kg) to generate ergonomic indicators and summary reports in Excel.

We used the software outputs to describe and compare:

- peak joint angles (e.g., trunk flexion, shoulder elevation),
- time spent in predefined posture risk zones (green for low risk, yellow for moderate risk, red for high risk),
- frequency of high-risk events,
- estimated loads (e.g., lumbar compression and joint moments), and
- an overall composite MSD risk score.

Because this is a single-subject, short-duration pilot, we report descriptive comparisons only (no statistical testing). We focus on how tasks differ in peak-load risk (short, high-intensity events) versus cumulative postural exposure (longer, repeated non-neutral postures), and we use these patterns to point to practical workplace changes (layout, heights, loads, tools, and task rotation).

3   Results

3.1   Placing and retrieving a 16 kg box on and from a mid-level shelf

Overall, the two 16 kg tasks produced a very similar ergonomic profile. Both were rated as significantly increased risk for MSDs with a score of 32 or higher (e.g., placing the box was scored with 36,88), which indicates that:

- Physical overstrain is possible even for normally resilient individuals.
- Complaints (pain) may occur with dysfunction, usually reversible, without morphological manifestation.

In both cases, the low back was the primary contributor to the score. The peak low-back loading looked like this:

- Peak lumbar disc compression reached 5,3 kN during the main lift phase.
- The software flagged this lift moment as a high or even extreme risk low-back event, as seen in Figure 2.

Force exposure	Score	Stress	NIOSH Action Limit, DGUV-traffic light
Cervical disc compression (Max.)	1	low	
Cervical disc compression (Duration)	1	low	
Lumbar disc compression (Max.)	3,5	extreme	
Lumbar disc compression (Duration)	3	high	
Shoulder moment left (Max.)	3	high	
Shoulder moment right (Max.)	3,5	extreme	
Shoulder moment left (Duration)	2	medium	
Shoulder moment right (Duration)	3	high	
Load (Max.)	2	medium	
Load (Duration)	2	medium	

Figure 2: NIOSH action limits for placing a 16kg box onto a mid-level shelf
Source: Own

Trunk posture and twisting:

- Peak trunk inclination was about 77° (noted during reaching/pulling and handling).
- Trunk rotation remained limited, so twisting did not appear to drive risk in these trials.
- Most of each task stayed in green/yellow zones, with red-zone exposure concentrated around the lift moment.

Upper-limb and neck posture:

- Arm elevation peaked at around 106°, therefore shoulder moments and durations also posed a high risk in this activity.
- Neck posture stayed largely neutral, and the neck was not highlighted as a key risk region for these tasks.

3.2 Retrieving a lightweight box from a high shelf with and without a ladder

This comparison shows a clear posture shift when the worker uses a ladder. The overall MSD risk score was reduced from 33 (no ladder) to 31 (with ladder). Using the ladder removed the brief high-load moments at the low back and reduced the peak compression value:

- Time spent in the red zone was eliminated: from 7 minutes and 59 seconds to zero.
- Peak value (max): reduced from 4,2 kN to 3,4 kN.

There was also an improvement in the trunk inclination:

- Time spent in red zone was reduced from 5 minutes 53 seconds to 0 seconds and in the yellow zone from 35 minutes 53 seconds to 13 minutes and 8 seconds.
- Peak trunk inclination: from 79° to 37°.

As can be seen in Figures 3 and 4, the ladder reduced both the peak overhead reach and the time spent in the highest arm-elevation zone.

Figure 3: Arm elevation of the right hand without the ladder
Source: Own

Figure 4: Arm elevation of the right hand with the ladder
Source: Own

The only trade-off was the radial/ulnar deviation of left wrist - likely due to grip/hand positioning during reach or placement of the ladder:

- The percentage in the yellow zone increased from 12 % to 56 %.
- Number of individual red events increased from 4 to 8.
- Peak deviation (max): from 19,6° to 26,2°.

3.3 Lightweight box packing

This task produced the clearest cumulative exposure pattern: low external load, but frequent and sustained non-neutral postures, especially for the low back and shoulders. Figure 5 shows the results of analysis with the score of 31,75, which falls into the moderately increased risk zone, this implies the following:

- Physical overstrain is possible in individuals with reduced resilience.
- Fatigue, minor adjustment complaints that can be compensated during leisure time.
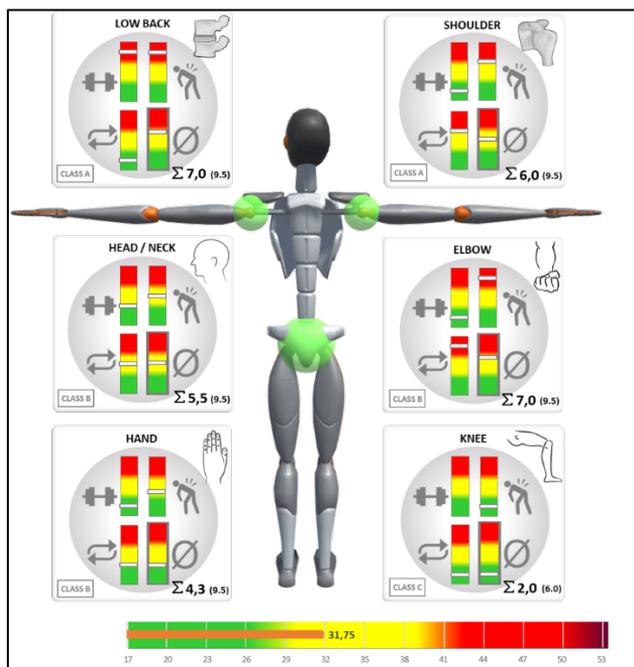
Figure 5: General analysis of lightweight box packing
Source: Own

Unlike the 16 kg lifts, the score was driven by time in awkward postures and repetition, not force. The key feature was how much of that time the worker spent away from neutral posture (yellow/red exposure accumulating across many small actions). If we look at the low-back and trunk posture, we come across the following:

- Peak trunk flexion reached about 86°, especially when the worker bent to pick items from a low location (e.g., near floor level).
- Cumulative exposure was substantial:
- about 21 % of task time in red-zone trunk posture,
- and about 39 % in yellow-zone moderate flexion.
- Lumbar compression forces stayed out of the red zone (less than 3,4 kN) for 73 % of the task time, so the risk came mainly from repeated bending and sustained flexion rather than heavy load.

The shoulders and arms were also at higher risk for MSD risk:

- Reaching and placing actions increased shoulder demand.
- The left shoulder peak elevation reached 92° during higher or farther reaches.
- The right shoulder showed many yellow events, consistent with frequent reach cycles during packing.

Neck posture alternated between forward flexion (looking down during bending) and neutral while working at the table; neck flexion around 30° occurred during bent phases and contributed to moderate exposure. Left wrist abduction also appeared during the packing, with multiple moderate and high-risk events when the wrist moved outside the neutral position.

3.4 Carrying a 10 kg box downstairs (from 3rd to 1st floor)

PHYSICAL STRESS	low (75%)		medium (25%)		high (10%)		Break 0:00 (h:m) 0%
	Time %	Dose/day (h:m:s)	Time %	Dose/day (h:m:s)	Time %	Dose/day (h:m:s)	Risk level (MSD)
Trunk inclination	89%	00:53:08	11%	00:06:52	0%	00:00:00	low
Lumbar disc compression	86%	00:51:28	8,2%	00:04:55	6,0%	00:03:38	low
Load	54%	00:32:24	46%	00:27:36	0%	00:00:00	medium
Head torsion	82%	00:49:25	15%	00:08:52	3%	00:01:42	low
Head inclination	34%	00:20:32	32%	00:19:27	33%	00:20:01	high
Cervical disc compression	73%	00:43:45	25%	00:14:44	3%	00:01:30	low
Arm elevation left	50%	00:30:13	42%	00:25:22	7%	00:04:25	medium
Arm elevation right	53%	00:31:49	44%	00:26:17	3%	00:01:54	medium
Shoulder moment left(STA)	0%	00:00:00	0%	00:00:00	0%	00:00:00	N/A
Shoulder moment left (DYN)	80%	00:48:15	20%	00:11:45	0%	00:00:00	low
Shoulder moment right (STA)	0%	00:00:00	0%	00:00:00	0%	00:00:00	N/A
Shoulder moment right (DYN)	84%	00:50:31	16%	00:09:29	0%	00:00:00	low
Above-shoulder work left	94%	00:56:07	3%	00:01:35	4%	00:02:18	low
Above-shoulder work right	95%	00:56:56	3%	00:01:56	2%	00:01:08	low
Velocity	84%	00:50:07	13%	00:07:40	4%	00:02:11	low
Wrist flexion/extension left	93%	00:56:01	7%	00:03:59	0%	00:00:00	low
Wrist flexion/extension right	94%	00:56:26	6%	00:03:28	0%	00:00:00	low
Wrist abduction left	63%	00:37:57	26%	00:15:28	11%	00:06:35	high
Wrist abduction right	99%	00:59:15	1%	00:00:45	0%	00:00:00	low
Knee flexion left	72%	00:42:57	24%	00:14:31	4%	00:02:32	low
Knee flexion right	70%	00:42:15	26%	00:15:36	4%	00:02:09	medium
Forearm rotation left	23%	00:13:32	19%	00:11:40	58%	00:34:48	high
Forearm rotation right	56%	00:33:28	19%	00:11:42	25%	00:14:51	high
Grasp space left	N/A	00:00:00	N/A	00:00:00	N/A	00:00:00	N/A
Grasp space right	N/A	00:00:00	N/A	00:00:00	N/A	00:00:00	N/A

DATABASE (time-weighting and daily dose)

Figure 6: Times and MSD risks of carrying a box down the stairs
Source: Own

This task showed a different pattern than the 16 kg lifts: no single extreme peak but sustained moderate load and repetition over the period of the task. Figure 6 shows the risk levels for MSDs for different body sections and the time spent under different physical stress zones, if we consider that the task is repeated many times throughout the worker's day.

The overall MSD risk score was 32,75 points (significantly increased risk). Risk came from duration under load and repeated stepping, not from brief high-force spikes. A single task lasted 1 minute and 13 seconds (down two flights of industrial stairs).

We synthesized the following information for low-back loading and trunk posture:

– Lumbar compression stayed around 1,5-2,0 kN during most of the descent, which is lower than the heavy-lift peaks but sustained.
– Trunk angle varied with each step (small cycles rather than a single bend-and-return) but mostly stayed in the neutral position.

Knees went through repeated flexion-extension cycles across the stair steps, with knee flexion peaking at 75° during stepping. The software did not flag the knee angles as extreme, but the repetition count contributed to the overall risk profile (repeated cycles under load). Arms and shoulders stayed relatively stable while holding the box close (generally low risk compared with packing or overhead work). Neck posture showed a strong forward flexion (looking down the stairs), around 20-25° for much of the task, with 32 % in the yellow zone and 33 % in the red zone.

4   Discussion

This study shows how wearable full-body motion capture combined with Scalefit outputs can describe warehouse task demands in a way that supports practical changes. Across tasks, the overall scores clustered in the moderately to significantly increased risk range for MSDs, which is in line with similar research (Zhao et al., 2022; Adhaye & Jolhe, 2023). The 16 kg box handling tasks were defined by short peak-load events (mainly low back), while packing showed longer time in non-neutral postures (low back and shoulders) with low external force. High-level picking without a ladder shifted risk to overhead shoulder and trunk posture, whereas using

a ladder reduced upper-body load but introduced some wrist strain. The stair-carrying task sat between these patterns, with sustained moderate load over a longer duration. These differences matter because they imply different controls: reducing peak spinal load for heavy handling versus reducing reach and bend time for packing.

The 16 kg box handling tasks reflect a **peak-load** risk profile. The overall rating stayed moderate because tasks were short, but the lift phase produced high low-back loading close to common action thresholds used in practice (e.g., values often referenced in NIOSH-based guidance) (Barim & Lu, 2020; Matijevich et al., 2021). This matters because repeated exposure to short high-load events can raise risk even when most of the task looks acceptable by posture time alone. Controls should aim to reduce peak spinal load: store heavier items near waist height, keep the load close, reduce load mass per lift, and use aids and/or ergonomic tools when frequency is high.

For the following task, using the **ladder reduced overall risk** and, more importantly, shifted the task away from high trunk and low-back loading and from sustained overhead reaching. In the no-ladder condition, the main exposure came from reaching high from the floor, which drove high trunk inclination and shoulder elevation. With the ladder, those upper-body demands dropped to mostly moderate levels, but the main trade-off appeared at the hand: the ladder condition increased left wrist deviation, likely due to grip and hand position during handling at height. In practice, this supports using ladders or step platforms for high picking, but pairing them with simple changes that protect the wrist (better handholds, two-hand grip, and placing the load closer to the body) (Hilmi, Hamid, & Ibrahim, 2024).

The packing task reflects a **cumulative exposure** profile. Loads were low, but the worker spent a large share of time in non-neutral trunk and shoulder postures. That matches the broader point in ergonomics literature that "light" work can still cause MSDs through repeated bending and reaching (Zhao et al., 2022). The practical priority is workstation and layout change: raise pickup points, keep high-use items in near reach, and set work height to limit shoulder elevation. Rotation and short breaks can help when packing runs for long periods, but redesign should come first when the layout is the main driver of the worker's posture (Sahu & Pandit, 2025).

The stair-carrying task showed **sustained moderate load** over a longer duration. It did not create one large peak, but continuous carrying and repeated stepping under load can drive fatigue and steady low-back demand. Practical options include reducing manual carries between floors, using lifts or routes that avoid stairs, and setting limits on carry duration and frequency.

Regarding the methodology used, the workflow supports faster and more objective assessment than purely observational approaches (Medved et al., 2025). Wearable motion capture can capture dynamic postures and peak events that are easy to miss by eye and can support rapid post-task reporting for decisions in the field (Lind et al., 2023; Humadi et al., 2021). Systems that give clear summaries and visual feedback can also support training and communication with managers and workers (Lind et al., 2020).

This study also had some limitations. This is a single-subject pilot with short trials, so results reflect one worker's technique and one setup. More workers and longer recordings would represent variation and fatigue across the shift and offer greater generalizability (this is also the main idea for future studies). Also, the overall risk score relies on a proprietary composite; the most defensible reporting approach is to show the core exposures (time in posture zones, peaks, estimated loads) alongside the score, using the score mainly for within-study comparison (Ciccarelli et al., 2025).

5   Conclusion

This study presents a practical field workflow that links wearable full-body motion capture (Xsens) with Scalefit outputs to describe physical load in warehouse work in a way that supports ergonomic action. Although the overall MSD risk scores clustered in the moderate to high range, the task profiles differed: 16 kg box handling showed short peak low-back loading, high-level picking without a ladder shifted risk to overhead shoulder and trunk posture, lightweight packing showed longer exposure to non-neutral trunk and shoulder postures, and stair-carrying showed sustained moderate demand over time. These differences matter because they imply different controls: reducing peak load for heavy handling (weight, storage height, aids), using a ladder when reaching higher shelves, reducing bend and reach time for packing (work height and layout), and reducing stair-carrying where possible (routing and lifts).

Viri in literatura

Adhaye, A. M., & Jolhe, D. A. (2023). Ergonomic assessment for designing manual material handling tasks at a food warehouse in India: A case study. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 33(6), 499-520.

Balantič, Z., Polajnar, A., & Jevšnik, S. (2016). Ergonomija v teoriji in praksi. Ljubljana: Nacionalni inštitut za javno zdravje, 357-83.

Barim, M. S., & Lu, M.-L. (2020, October 13). *Assessing lifting risk factors using wearable motion sensors*. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://blogs.cdc.gov/niosh-science-blog/2020/10/13/imu-sensors/

Ciccarelli, M., Papetti, A., & Germani, M. (2025). Empowering industry 5.0: automated sensor-based ergonomic risk assessment. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 1-23.

Hilmi, A. H., Hamid, A. R. A., & Ibrahim, W. A. R. A. W. (2024). Recent Advances in Ergonomic Studies on Material Handling: Mitigating Musculoskeletal Risks and Enhancing Worker Safety. *Malaysian Journal of Ergonomics (MJEr)*, 6, 52-64.

Humadi, A., Nazarahari, M., Ahmad, R., & Rouhani, H. (2020). Instrumented ergonomic risk assessment using wearable inertial measurement units: Impact of joint angle convention. *IEEE Access*, 9, 7293-7305.

Krishnan, A., Yang, X., Seth, U., Jeyachandran, J. M., Ahn, J. Y., Gardner, R., ... & Manohar, K. (2025). Data-driven ergonomic risk assessment of complex hand-intensive manufacturing processes. *Communications Engineering*, 4(1), 45.

Lind, C. M., Abtahi, F., & Forsman, M. (2023). Wearable motion capture devices for the prevention of work-related musculoskeletal disorders in ergonomics—An overview of current applications, challenges, and future opportunities. *Sensors*, 23(9), 4259.

Lind, C. M., Diaz-Olivares, J. A., Lindecrantz, K., & Eklund, J. (2020). A wearable sensor system for physical ergonomics interventions using haptic feedback. *Sensors*, *20*(21), 6010.

Matijevich, E. S., Volgyesi, P., & Zelik, K. E. (2021). A promising wearable solution for the practical and accurate monitoring of low back loading in manual material handling. *Sensors,* 21(2), 340.

Medved, T., Balantič, Z., & Jarc Kovačič, B. (2025). Optimizacija ocene ergonomskih tveganj z uporabo pospeškomerov v 4D okolju. In 44th International Conference on Organizational Science Development: Human Being, Artificial Intelligence and Organization (pp. 597–610). Univerza v Mariboru, Univerzitetna založba. https://doi.org/10.18690/um.fov.3.2026.45

Rybnikár, F., Kačerová, I., Hořejší, P., & Šimon, M. (2022). Ergonomics evaluation using motion capture technology—literature review. *Applied Sciences*, 13(1), 162.

Sahu, A., & Pandit, S. (2025). Occupational ergonomic research and contextual design execution of a new workstation to reduce work-related musculoskeletal disorders (WRMSDs) among Dhokra handicraft artisans: an unorganized sector of India. *Industrial health*, *63*(6), 579-596.

Simon, S., Dully, J., Dindorf, C., Bartaguiz, E., Walle, O., Roschlock-Sachs, I., & Fröhlich, M. (2024). Inertial motion capturing in ergonomic workplace analysis: Assessing the correlation between RULA, upper-body posture deviations and musculoskeletal discomfort. *Safety*, 10(1), 16.

Zhao, Y. S., Jaafar, M. H., Mohamed, A. S. A., Azraai, N. Z., & Amil, N. (2022). Ergonomics risk assessment for manual material handling of warehouse activities involving high shelf and low shelf binning processes: application of marker-based motion capture. *Sustainability*, 14(10), 5767.