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Ergonomic and Musculoskeletal Risk Patterns Among Roofers and Non-roofers: Evidence from a Comparative Field Study

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Roofing is one of the most physically demanding construction trades, yet limited research has quantified how its unique postural demands contribute to work-related musculoskeletal disorders (WMSDs). This study addresses this gap through a field-based comparison of musculoskeletal pain and ergonomic exposure between roofers and non-roofers. A structured questionnaire was administered to 32 construction workers (16 roofers and 16 non-roofers) to assess self-reported pain intensity across body regions and foot zones, along with the duration and frequency of awkward working postures. Descriptive statistics, independent-samples t-tests, and Mann–Whitney U tests were used to examine group differences. Roofers reported significantly higher total body pain, feet pain, and a greater number of painful body zones than non-roofers ($p < .05$). Toe-specific Pain was notably greater among roofers ($p = .003$), suggesting excessive forefoot strain caused by frequent kneeling, stooping, and balancing on sloped surfaces. Roofers also experienced greater exposure to awkward postures, despite working comparable hours. These findings underscore the importance of implementing improved ergonomic practices (ergonomic training and task rotation), properly fitted footwear, and advanced insole technologies to monitor and mitigate WMSDs, thereby fostering safer, healthier, and more productive work environments.

Keywords: Roofers, Ergonomics, Work-related Musculoskeletal Disorders, Forefoot Strain, Ergonomic Exposure

Introduction

The construction industry remains one of the most hazardous occupational sectors worldwide, accounting for over one-third of all work-related injuries and fatalities according to the Bureau of Labor Statistics (BLS, 2023). Notably, workers in physically demanding roles, such as roofers, farmers, plumbers, masons, steel workers, and laborers, perform strenuous tasks under extreme environmental conditions. Among these trades, roofers are particularly vulnerable due to their frequent work on sloped surfaces, often in direct sunlight, while wearing rigid and thermally insulated but not job-specific insoles of footwear. These factors could significantly elevate the risk of slips, falls, fatigue, and work-related musculoskeletal disorders (WMSDs), especially in the feet, knees, and lower back. Studies have identified the back, shoulders, knees, hands, and feet as the most affected areas for musculoskeletal pain among roofers (Welch et al., 2009; Fredericks et al., 2005). However, most evidence is derived from either laboratory-based biomechanical assessments or trade-aggregated

analyses that do not explicitly compare roofers with other construction workers under field conditions (Breloff et al., 2019; Antwi-Afari et al., 2022).

Guided by prior biomechanical evidence showing increased lower-limb muscle activation, forefoot plantar pressure, and postural instability during sloped roofing tasks (Breloff et al., 2019; Dutta et al., 2020; Kayastha et al., 2024), this study examines task-specific differences in pain burden, awkward posture exposure, and foot-pain localization. We hypothesize that roofers will exhibit (i) higher overall musculoskeletal pain burden, (ii) greater duration and frequency of awkward working postures, and (iii) disproportionately higher forefoot (toe) pain, reflecting elevated plantar loading and balance demands associated with sloped roofing work.

Literature Review

WMSDs are among the most common health problems in construction, having nearly one-third of all work-related injuries worldwide (BLS, 2023; Dong et al., 2021). Among many construction trades, roofers face particularly high ergonomics risks as they work on steep, uneven, and hot surfaces while performing physically demanding tasks such as lifting, kneeling, stooping, and materials (Breloff et al., 2019; Almaskati et al., 2024). Compared to other construction occupations, roofing is viewed as an exceptionally high-risk field, as roofing workers face a fatality rate more than triple the norm for the construction sector as a whole (Dong et al., 2013; Fredericks et al., 2005; Moore & Wagner, 2014). Roofing fatalities rose by 7.8% in 2021 according to Bureau of Labor Statistics data reported by Roofing Contractor (Gray, 2023). In 2023, roofing contractors represented the largest share of construction fatalities related to falls, slips, and trips, accounting for 26.0% of deaths (110 fatalities), followed by residential building construction at 14.7% (62 fatalities), according to the Bureau of Labor Statistics (BLS, 2025). Biomechanical studies have demonstrated that roof slope, work technique, and pace are associated with increased low-back loading and altered lower-limb mechanics (Wang et al., 2017). Laboratory and field experiments further show that kneeling and cross-slope walking on inclined roofs significantly increase muscle activation, joint stress, and postural instability (Breloff et al., 2019a, 2019b; Dutta et al., 2020). Field studies conducted in Texas have reported that roofers most frequently experience pain in the feet, back, and knees, suggesting that lower-extremity loading plays a central role in roofing-related WMSDs (Kisi & Kayastha, 2024).

Recent advancements in wearable technologies such as pressure sensors, inertial measurement units (IMUs), and surface electromyography (sEMG) have allowed for detailed assessments of postural risk and musculoskeletal loading in high-risk occupations (Mahmud et al., 2025). Kayastha et al. (2025) observed that toe regions experience the highest peak pressure across all slope angles, even when total plantar force decreases, while Acharya et al. (2025) reported a 36% increase in center-of-pressure displacement on 30° slopes and a 52% rise in toe instability. These findings suggest that sloped roofing tasks cause substantial forefoot strain. However, most of these studies were performed in controlled laboratory settings, limiting their generalizability to real-world roofing environments.

Despite these advances, few field-based studies have directly compared roofers and non-roofers with respect to pain localization, ergonomic exposure, and cumulative musculoskeletal burden. Existing research often examines posture or slope effects in isolation and does not integrate self-reported pain with exposure duration under real working conditions. The present study addresses this gap by combining field-based questionnaire data with ergonomic exposure metrics to evaluate task-specific musculoskeletal risk patterns across trades.

Research Objectives

The primary objective of this study was to quantify and compare task-specific ergonomic exposure and musculoskeletal pain outcomes between construction roofers and non-roofers, with emphasis on pain burden, awkward-posture exposure, and localized foot pain associated with sloped roofing work.

Specific Objectives

1. Compare overall musculoskeletal pain burden (total body pain, total foot pain, and number of painful body regions) between roofers and non-roofers.
2. Evaluate differences in ergonomic exposure, measured by the duration and frequency of awkward postures, between the two groups.
3. Examine trade-specific foot pain patterns, particularly whether forefoot (toe) pain is disproportionately higher among roofers due to elevated plantar loading and balance demands on sloped surfaces.

Methodology

This methodology describes the study design, characteristics of participants, procedures for data collection and experimental setup, as well as the statistical techniques used as described below.

Participants

A total of 32 construction workers voluntarily participated, comprising 16 roofers and 16 non-roofers from other trades (construction laborers, rodbusters, framers/drywall installers, and electricians), recruited from construction sites located near San Marcos and Kyle, Texas, selected to capture variability in work tasks, site conditions, and ergonomic exposures rather than from a single project. The sample represented a broad worker profile. Approximately one-third of participants were aged 50 years or older, with the remainder distributed across 30–39 and 40–49 age groups. Over half reported more than 10 years of construction experience, including many with over 20 years. Most participants worked more than 40 hours per week, and nearly one-third exceeded 50 hours. Regarding ergonomic exposure, most workers reported 1–3 hours of awkward postures per day, while about one-third reported more than 3 hours daily. Inclusion criteria required participants to be actively employed in construction, over 18 years old, and have at least one year of work experience. Workers with recent injuries or medical conditions unrelated to construction activity were excluded.

Data Collection and Procedure

Data were collected through brief one-on-one interviews using a structured questionnaire administered in English and Spanish. The questionnaire used in the present study builds on the Nordic Musculoskeletal Questionnaire (Crawford, 2007) and was initially developed for a prior large-scale investigation examining musculoskeletal pain and productivity among Hispanic construction workers in Texas (Kisi & Kayastha, 2024). This questionnaire was enhanced in the present study to include refined measures of ergonomic exposure (e.g., duration and frequency of awkward postures), localized foot pain assessed by anatomical zones, and footwear-related discomfort. Interviews were conducted during workers' short breaks and each session lasted approximately 15–20 minutes. The survey captured the following information on different body regions (Figure 1/2).

- Demographics: Age, weight, height, and years of experience.
- Ergonomic exposure: Average daily hours and weekly days spent in awkward postures
- Musculoskeletal pain indicators: Pain presence (Yes/No) and intensity scores for major body regions (shoulder, back, hip, knee, ankle, feet) and foot zones (toes, metatarsal, midfoot, heel) in terms of no pain, low pain, high pain, and very high pain.

- All pain ratings were based on self-reported discomfort levels experienced

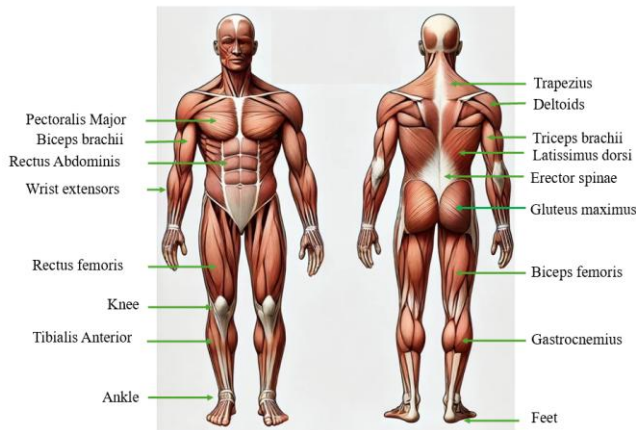


Figure 1: Major body region

Source: Adapted from Netter's Atlas of Human Anatomy, 2022

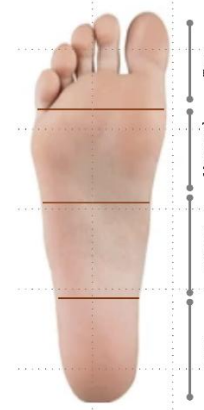


Figure 2: Foot zones

Source: created by the author

Pain Measures and Conceptual Framework

The independent variable was trade group (roofers = 1; non-roofers = 0). Outcome variables included composite pain measures (Total Body Pain, Total Feet Pain, Pain Zone Count, and Total Pain Index [%]) and localized pain severity for four-foot zones (toes, metatarsal, midfoot, heel). Pain intensity for each body region and foot zone was self-reported using a four-level ordinal scale coded as 0 = no pain, 1 = low pain, 2 = high pain, and 3 = very high pain. Participants were asked to report pain and discomfort experienced during their typical work activities over the past seven days. Total Body Pain was computed as the sum of pain scores across all assessed major body regions (e.g., shoulders, back, hips, knees, ankles, and feet). Total Feet Pain was calculated as the sum of pain scores across the four foot zones. Pain Zone Count represents the number of distinct anatomical regions reporting any pain (score ≥ 1). R1-05 The Total Pain Index (%) was developed to quantify overall musculoskeletal pain burden and to have direct comparison of cumulative pain burden between roofers and non-roofers. The TPI was calculated as:

$$\text{TPI (\%)} = \left(\frac{\sum_{i=1}^n P_i}{3n} \right) \times 100$$

where P_i denotes the reported pain score for the i^{th} anatomical location and n represents the total number of evaluated locations.

Conceptually, this study assumes that task-specific ergonomic exposures, particularly prolonged awkward postures on sloped surfaces that increase localized mechanical loading of the lower extremities, especially the forefoot. This localized loading contributes to foot pain, which aggregates into a higher overall musculoskeletal pain burden. Accordingly, trade group was modeled as the primary exposure, with ergonomic posture as an intermediate factor, localized and composite pain measures as outcomes. Based on prior biomechanical evidence linking sloped work, forefoot loading, and awkward postures to musculoskeletal strain, it was hypothesized that roofers would exhibit (i) higher cumulative musculoskeletal pain burden, (ii) greater duration and frequency of awkward-posture exposure, and (iii) disproportionately higher forefoot (toe) pain compared with non-roofers.

Statistical Analysis

Data were analyzed using IBM SPSS (v.29). Descriptive statistics summarized participant characteristics and pain prevalence. Parametric or nonparametric tests were applied as appropriate based on data distribution, with significance set at $p < .05$. Participation was voluntary, no identifying data were collected, and all procedures followed Texas State University ethical guidelines.

Results

Normality and Assumptions Checks

Prior to inferential analyses, data normality was evaluated using the Shapiro–Wilk test. Pain-related composite variables (Total Body Pain, Total Feet Pain, Pain Zone Count, and Total Pain Index) were approximately normally distributed ($p > .05$), supporting the use of parametric tests. Levene’s tests for equality of variances were conducted for all composite pain variables and were non-significant ($p > .05$), indicating homogeneity of variances between groups. Whereas ergonomic exposure variables (Awkward Hours per Day and Awkward Days per Week) were non-normally distributed ($p < .05$), were therefore analyzed using non-parametric methods. Demographic variables (age, years of experience, and body weight) showed mild skewness, used for descriptive purposes. So, independent-samples t-tests were applied to composite pain outcomes that satisfied parametric assumptions, whereas Mann–Whitney U tests were used for non-normally distributed exposure measures.

Participant Characteristics

Descriptive statistics for the 32 construction workers (16 roofers and 16 non-roofers) are presented in Table 1a and Table 1b. Participants had an average age of 42.8 ± 16.4 years, a mean of 15.9 ± 11.0 years of professional experience. On average, workers reported spending 2.7 ± 2.0 hours per day in awkward postures across 4.7 ± 1.9 days per week, indicating consistent ergonomic strain across both groups.

Prevalence of Pain, Discomfort, and Exposure

As shown in Table 1a, roofers ($n = 16$) more frequently reported body pain ($n = 12$), foot pain ($n = 15$), injury ($n = 10$), and awkward postures ($n = 15$) than non-roofers ($n = 9, 13, 7,$ and 12 , respectively) in Table 1b. Reports of discomfort, fatigue, and mental stress were low in both groups but occurred slightly more often among roofers.

Table 1a. Prevalence of Self-Reported Pain, Discomfort, and Exposure /Roofers ($n = 16$)

Variable	Yes	No	Interpretation
Pain (anybody region)	12	04	The majority reported some form of body pain
Injury	10	6	Over half reported prior or current injury
Discomfort	5	11	Nearly one-third reported physical discomfort
Fatigue	4	12	Some roofers reported noticeable fatigue
Mental stress	1	15	Very few reported stress symptoms
Awkward posture	15	1	Most frequently work in awkward postures
Any foot pain	15	1	Almost all reported foot-related pain
Trade group	—	—	Roofing workers only

Table 1b. Prevalence of Self-Reported Pain, Discomfort, and Exposure/Non-Roofers (n = 16)

Variable	Yes	No	Interpretation
Pain (anybody region)	9	7	About half reported some form of pain
Injury	7	9	Less than half reported injury history
Discomfort	3	13	Few reported physical discomfort
Fatigue	2	14	Fatigue is less commonly experienced
Mental stress	1	15	Very few reported stress symptoms
Awkward posture	12	04	Most workers experienced awkward postures
Any foot pain	13	03	The majority experienced foot pain
Trade group	—	—	Non-roofing trades

Pain Comparison Between Roofers and Non-roofers

Independent samples *t*-tests were conducted to evaluate differences in overall and localized pain intensity between roofers and non-roofers (Table 2). Roofers reported significantly higher total body pain ($M = 7.56$, $SD = 3.54$) than non-roofers ($M = 4.94$, $SD = 2.74$), $t(30) = -2.34$, $p = .026$, Cohen's $d = 0.83$, representing a large effect and indicating a substantial increase in whole-body pain burden with clear practical relevance. Similarly, total foot pain was greater among roofers ($M = 3.81$, $SD = 1.91$) than non-roofers ($M = 2.31$, $SD = 1.66$), $t(30) = -2.37$, $p = .024$, $d = 0.84$, suggesting a meaningful elevation in foot-related discomfort likely to affect balance, endurance, and work performance. Roofers also reported a higher number of painful body zones ($M = 6.25$, $SD = 2.79$) compared to non-roofers ($M = 4.00$, $SD = 2.10$), $t(30) = -2.58$, $p = .015$, $d = 0.91$. Finally, the Total Pain Index was significantly higher among roofers ($M = 23.69$, $SD = 10.11$) than non-roofers ($M = 15.11$, $SD = 7.62$), $t(30) = -2.71$, $p = .011$, $d = 0.96$, reflecting a broader distribution of musculoskeletal strain rather than isolated symptoms. As a robustness check, nonparametric Mann–Whitney U tests were also conducted for the composite pain variables and yielded the same pattern of statistically significant group differences.

Table 2. Comparison of Pain Variables Between Roofers and Non-roofers

Variable	Other Trades (M ± SD)	Roofers (M ± SD)	<i>t</i> (df)	<i>p</i>	Cohen's <i>d</i>
Total Body Pain	4.94 ± 2.74	7.56 ± 3.54	-2.34 (30)	0.026	0.83
Total Feet Pain	2.31 ± 1.66	3.81 ± 1.91	-2.37 (30)	0.024	0.84
Pain Zone Count	4.00 ± 2.10	6.25 ± 2.79	-2.58 (30)	0.015	0.91
Total Pain Index (%)	15.11 ± 7.62	23.69 ± 10.11	-2.71 (30)	0.011	0.96

Note. Negative *t*-values reflect higher means for roofers (coded 1). All results are significant at $p < .05$.

Ergonomic (Awkward Posture) Exposure (Nonparametric Tests)

Mann–Whitney U tests were used to compare ergonomic exposure to awkward postures. Roofers reported significantly greater daily exposure (Mdn = 2.0) compared to other trades (Mdn = 1.0), $U = 62.0$, $p = .012$, $r = 0.45$, indicating a moderate effect. Similarly, roofers worked in awkward postures on more days per week (Mdn = 6.0) than non-roofers (Mdn = 3.0), $U = 58.5$, $p = .008$, $r = 0.48$. These results align with prior findings that roofing tasks require frequent bending, kneeling, and balancing

on inclined surfaces (Antwi-Afari et al., 2022; Breloff et al., 2019). Roofers exhibit higher ergonomic risk exposure, which likely contributes to their elevated pain prevalence and intensity.

To identify which foot zones are most affected, Mann–Whitney U tests were conducted for the toes, metatarsal, midfoot, and heel as written (see Table 3). Roofers showed significantly greater pain in the toe region ($U = 64.0$, $Z = -3.00$, $p = .003$), suggesting increased forefoot strain during balance and climbing tasks on sloped surfaces. No significant differences were found for the metatarsal ($p = .552$), midfoot ($p = .720$), or heel ($p = .317$). This pattern aligns with biomechanical studies showing that forefoot pressure increases with slope inclination and prolonged kneeling (Breloff et al., 2019; Kayastha et al., 2024). Toe pain emerged as the most significant differentiator between trades.

Table 3. Comparison of pain severity by foot zone between roofers and Non-roofers (Mann–Whitney U test, $N = 32$)

Foot Zone	Roofers Mean Rank	Others Mean Rank	p-value	Interpretation
Toes	20.5	12.5	0.003	Significant — roofers report more toe pain
Metatarsal	17.4	15.6	0.552	Not significant
Midfoot	16.9	16.1	0.72	Not significant
Heel	18	15	0.317	Not significant

Note. Mann–Whitney $U = 64.0$ for toe pain, significantly higher ranks among roofers.

Discussion

This study explored the differences in work-related musculoskeletal pain and ergonomic exposure between construction roofers and non-roofers. The findings revealed that roofers tend to suffer more from body and foot pain, with discomfort spread across more areas of the body and higher overall pain levels. Even though both groups worked for comparable total hours per day, roofers spent more time in awkward positions and reported severe pain in their toes. This suggests that the nature of roofing work that requires frequent kneeling, stooping, and balancing on sloped and unstable surfaces puts extra stress on the lower body, causing more forefoot strain compared to non-roofers.

The pattern of the pain distribution observed in this study is consistent with earlier studies highlighting the unique risk faced by the construction roofers. Studies by Antwi-Afari et al. (2022) and Breloff et al. (2019) found that spending long hours in awkward positions while roofing showed to higher muscle activity and fatigue, especially in the lower body. According to Gautam et al. (2025), the right and left biceps femoris muscles show the highest activation during stooping on sloped roofing surfaces. This suggests roofers are at greater risk of fatigue and muscle strain, emphasizing the need for proper support and rest to prevent injuries. Similarly, Dutta et al. (2020) showed that kneeling and stooping on sloped surfaces greatly increase the strain on knee muscles, helping to explain the frequent reports of knee and leg pain among roofers. In addition, Antwi-Afari et al. (2023) noted that working on roof slopes raises pressure on the soles of the feet—particularly under the forefoot—aligning with the toe pain reported in the current study.

The consistent localization of pain in the forefoot is further supported by plantar pressure and balance studies. Kayastha et al. (2025) showed that toe regions sustain the highest pressure across slope angles, while Ho et al. (2010) and Chow and Lee (2024) observed forward shifts in plantar loading as roof slope increases. Acharya et al. (2025) reported a 36% increase in overall center-of-pressure

displacement on a 30° slope, with toe instability rising by 52% compared to flat surfaces. Neurological evidence further substantiates this interpretation. Herbert et al. (1995) identified that 42% of roofers exhibited abnormal vibrotactile thresholds in their toes, suggesting early-stage neuropathy linked to chemical exposure and repetitive mechanical strain.

Collectively, these findings highlight that roofing-specific tasks generate concentrated forefoot strain and elevated musculoskeletal burden beyond that experienced by other construction trades. This evidence highlights the need for ergonomic supports and better insole designs to reduce pain and protect roofers from long-term injuries. These findings have key implications for improving comfort and safety in roofing work. The higher pain among roofers' points to excessive pressure on the forefoot, showing the need for better-fitting shoes and customized job-specific insoles that spread pressure more evenly. As Buldt and Menz (2018) noted, many workers wear ill-fitting footwear, which contributes to pain and deformities. Incorporating smart insoles that track pressure, movement, and temperature in real time (Kayastha et al., 2024) can help detect fatigue and imbalance early.

Limitations

The sample size was small (32 participants), which limits how widely the results can be applied. Participants were recruited from construction sites in Central Texas, where high temperatures and heat exposure may influence posture, fatigue, and pain perception. via brief interviews during work breaks, which may have introduced time constraints and recall bias and may not fully capture real-time ergonomic conditions. Although administering the questionnaire in both English and Spanish improved inclusivity and participation, potential differences in translation, interpretation, and cultural perceptions of pain may have influenced how questions were understood and answered. R2-12 Although a structured questionnaire was used, the full instrument was not included in the main manuscript due to page limitations. The complete questionnaire is available upon reasonable request R2-15 The non-roofer group included workers from several construction trades with different job tasks and physical demands and do not work on sloped roofs. Future studies with larger samples should examine each trade separately to better capture task-related ergonomic risks and should also examine how the combination of slope angle, work duration, and heat exposure affects the body.

Conclusion

This study provides valuable insight to construction ergonomics by providing a direct, field-based comparison of ergonomics exposures and musculoskeletal pain outcomes between roofers and non-roofers. This approach has been largely absent in prior research, where laboratory simulations are highly emphasized. While previous studies show that roofing is physically demanding, they have not clarified how roofing-specific risks differ from those of non-roofers under real working conditions.

Despite working similar hours, roofers experience significantly greater total body and foot pain, and more frequent use of awkward postures, demonstrating that task-specific demand. Most importantly, the toe pain observed among roofers indicates that prolonged postures like kneeling, stooping, standing, and walking impose repetitive strain on the forefoot, highlighting the biomechanical intensity of roofing work and validating previous scientific studies. Notably, the consistent localization of pain in the toe (forefoot) region suggests that prolonged kneeling, stooping, standing, and walking on sloped surfaces impose repetitive mechanical strain on the forefoot. This field-based evidence strengthens existing biomechanical research by identifying a specific anatomical pattern of risk associated with roofing work. These findings highlight the need for trade-specific ergonomic interventions, including improved footwear and insole designs that better address forefoot loading and

balance demands unique to roofing, as well as ergonomic training and task-rotation strategies to reduce cumulative strain from prolonged non-neutral postures.

Future studies with larger samples and integrated biomechanical measurements may build on these results by examining how posture, slope, and environmental stressors such as heat interact to influence discomfort, balance, and musculoskeletal risk. While the present study is questionnaire-based, its findings provide a foundation for subsequent research that may explore the potential role of wearable, sensor-based approaches in understanding and mitigating ergonomic risks in roofing work.

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