EPiC Series in Built Environment

Volume 6, 2025, Pages 816–825

Proceedings of Associated Schools of Construction 61st Annual International Conference

Muscle Activation Patterns in Stooping Posture on Sloped Roofing Surfaces

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Roofing tasks frequently involve sustained awkward postures, such as stooping, which significantly elevate the risk of work-related musculoskeletal disorders (WMSDs). This study aimed to quantitatively assess muscle activation while stooping on a 30-degree sloped surface, a common posture in roofing activities. Seven healthy male participants were recruited, and muscle activity was monitored using surface electromyography (sEMG) sensors placed on twelve muscle groups, including the Biceps Femoris, Rectus Abdominis, and Rectus Femoris. The muscle activation data were normalized using maximum voluntary contraction (MVC) values, and the muscles were ranked based on their cumulative activation levels during the task. The analysis revealed that the Right and Left Biceps Femoris exhibited the highest levels of activation, significantly surpassing other examined muscle groups. These findings indicate a considerable demand on the Biceps Femoris during stooping, which could predispose workers to muscle fatigue and increase the risk of WMSDs. The results underscore the necessity of targeted ergonomic interventions, such as muscle-specific training programs and supportive devices, to alleviate strain and prevent long-term musculoskeletal injuries. Future research should investigate diverse postures, incorporate larger sample sizes, and include experienced roofing workers to enhance the applicability of the findings

Keywords: Muscle activation, Surface electromyography, Stooping, Roofing, Musculoskeletal disorders

Introduction

Awkward working postures like kneeling and stooping are common in construction roofing jobs. These positions are significant risk factors for WMSDs, which rank as the leading cause of non-fatal occupational injuries (Grzywiński et al., 2017; Antwi-Afari et al., 2018). According to the Bureau of Labor Statistics 2022, there were 2.4 recordable non-fatal injuries per one hundred full-time workers, with 1.5 per 100 cases leading to days off work (BLS, 2023).

Roofing is among the most hazardous jobs in construction. Roofers are three times more likely to face a fatal injury than that of other construction workers (Onuchukwu & Esmaeili, 2024). Falls are particularly dangerous, accounting for over three-fourths of fatalities in the roofing sector from 2003 to 2009 (BLS, 2012). Roofers spend over 75% of their time in awkward postures like stooping and kneeling, increasing their risk for WMSDs (CPWR, 2013).

The combination of working on sloped roofs and repetitive motions contributes to a high rate of WMSDs among roofers (Dulay et al., 2015). Awkward postures hinder muscle efficiency, leading to increased muscle activation and overload compared to natural positions (Kaushik & Charpe, 2008). Insufficient recovery time while in these postures can lead to injuries from overexertion or imbalance (Hofer et al., 2011).

Muscle activation occurs when the nervous system signals muscle fibers to contract, involving motor unit recruitment necessary for sustained contractions (Enoka & Duchateau, 2008; Riccobelli & Ambrosi, 2019). Muscle fatigue, defined as the inability to maintain desired force, can lead to WMSDs (Benwali et al., 2022). The nature of fatigue varies; it can be short-lived or chronic, impacting performance (Constantin-Teodosiu & Constantin, 2021).

Research has increasingly used wearable sensors to study muscle activation and the effects of awkward postures (Dutta et al., 2020). sEMG sensors record muscle electrical activity (Anderson et al., 2014). While earlier studies have focused on muscle activation during kneeling tasks, they often overlook other common roofing tasks. Existing research has primarily examined the physical environment, such as roof slopes, without fully addressing specific muscle activation patterns during other roofing tasks. Breloff et al. (2019), Dutta et al. (2020) and Wang et al. (2017) have been working on investigating the effects of slopes, working techniques and body kinematics of working on sloped surface. Study by Sakamoto & Swie (2003) and Salleh et al. (2020) have indicated the higher activation patterns in erector spinae, hamstrings and lumbar multifidus while stooping on plane surface. Nevertheless, no work related to finding the most activated muscle for stooping posture specific to roofing surface has been performed to date. The researchers aim to find the most activated muscle during stooping posture in a 30-degree sloped surface.

This study aims to identify the most activated muscle during stooping posture on a 30-degree sloped surface as stooping is one of the commonly encountered roofing postures (Jirsaraei et al., 2022). sEMG data was collected from seven participants using Cometa sensors while they maintained a stooping posture on a sloped surface.

Methodology

The methodology for this study was designed to investigate muscle activation patterns during stooping postures on sloped surfaces. It involved a multi-stage process, including experimental setup, participant recruitment, data collection, and analysis. The following sections detail the key aspects of the methodology, starting with the data collection process.

Data Collection

The experimental roof setup was designed based on scientific principles and insights gathered from informal discussions with roofers from two companies. Using this feedback, a mock-up roof of 8ftx8ft platform was constructed in the laboratory to simulate actual roofing environments. After getting IRB approval, participants were recruited to meet the target sample size of seven individuals. Screening was conducted via a Qualtrics survey and/or in-person questionnaire form. Prescreening was performed to assess participants' sleep quality, allergies to hydrogel, and history of musculoskeletal disorders or injuries. Participants signed consent forms and eligible participants were invited to the experimental setup.

Participants performed stooping posture on a 30-degree sloped surface as shown in Figure 1, with four repetitions of each task to collect sufficient muscle activation data. This study considers stooping as bending of the upper body forward while slightly bending the knees, while keeping the legs at

shoulder-width distance. The participants were asked not to put weight on their hands while stooping and their posture was validated by the research team. They were briefed on the study objectives and safety procedures, after which they consented to perform the experiment. Measurements such as blood pressure, body weight, and handgrip strength were also recorded for safety monitoring during the experiment.
During the preparation phase, sEMG sensors were attached to twelve muscles as shown in Figure 2 (Right and Left): Erectus Spinae, Rectus Femoris, Rectus Abdominis, Biceps Femoris, Tibialis Anterior, and Gastrocnemius. Sensor placement followed the guidelines from Atlas of Muscle

Figure 1. Participant Stooping using EMG sensor in 30-degree slope

Innervation Zones: Understanding Surface Electromyography and Its Applications (Barbero et. al, 2012) to ensure precise positioning over each muscle. Specific standardize exercises for muscle testing were conducted to measure the MVC of each muscle group, following established methodologies: lumbar extension for the erector spinae (Ambrose et al., 1997), sit-ups for rectus abdominis (Vera-Garcia et. al, 2000), isometric knee extension for rectus femoris (Noorkoiv et. al, 2014), isometric prone leg curl for biceps femoris (Muyor et al., 2020), foot dorsiflexion for tibialis anterior and foot plantarflexion for gastrocnemius (Murley, Menz, & Landorf, 2010).

To normalize muscle activation data, MVC measurements were taken three times for each muscle, with each measurement lasting 30 seconds. A five-minute rest period followed the MVC tests to prevent fatigue before participants proceeded with the experimental tasks.

The sEMG sensors used in this research were Cometa EMG PicoX and WaveX.. Cometa sensors were selected for their cost-effectiveness and compatibility with other equipment, including the MVN Movella motion capture system (Mohammed et al., 2023). Muscle activity data was recorded from the sEMG sensors. Specific event markers were used to segment task and rest periods to distinguish between exertion and recovery phases in the analysis. One-minute breaks were provided between task sets to prevent fatigue from impacting on data integrity. Participants performed stooping posture on a

30-degree sloped structure for four minutes, with one minute rest in between, repeated four times in a session.

Upon the experiment's completion, the participant was asked to relax and was monitored till the participant felt comfortable leaving the experimental setup.

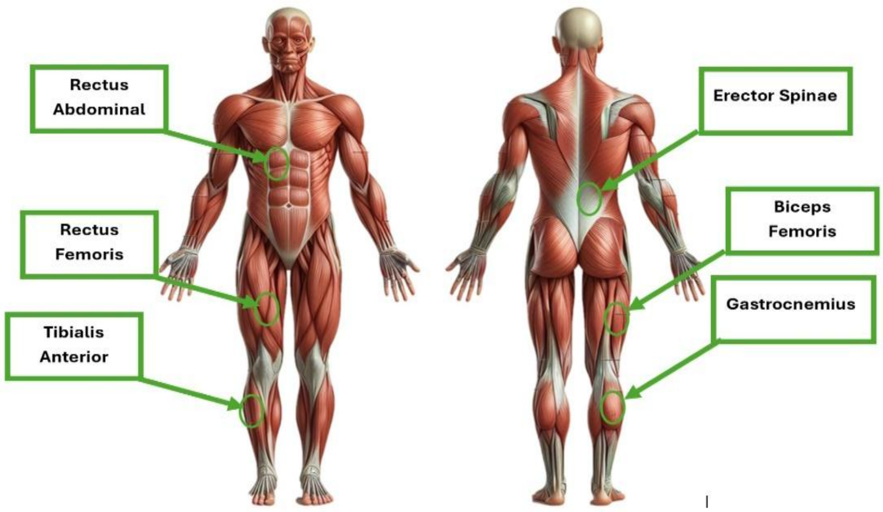

Figure 2. EMG sensor placement position in Muscle Groups

Data Analysis

The data analysis for this study involved several key steps, including data export, preprocessing, signal filtering, normalization, and statistical analysis. The first step involved exporting raw data captured from C3D files into CSV format, easing a structured analysis of muscle activity during the sessions. This approach aligns with established biomechanical data processing methods (Robertson et al., 2013).

For data preprocessing, Python was used in combination with the Pandas module, following best practices in biomedical signal processing (Merletti & Farina, 2016). The raw CSV files were separated into distinct activity sessions based on predefined event markers. Signal filtering was applied to raw EMG signals using established protocols (Stegeman & Hermens, 2007). A band-pass filter with cutoff frequencies of 0.5 Hz (low-pass) and 250 Hz (high-pass) was used to focus on the relevant frequency range of muscle signals, while a notch filter at 60 Hz was implemented to drop electrical noise interference, following recommendations by Konrad (2005).

After filtering, the data underwent normalization based on the maximum values obtained during the MVC calculation for each muscle group, adhering to standardized EMG processing protocols (Halaki & Ginn, 2012). This normalization allowed for comparisons of muscle use across participants and sessions, a method confirmed in many EMG studies (Burden, 2010). Cumulative muscle activation was computed for each session, with muscles ranked from 1 to 12 based on their level of activation, following methodologies set up by Vigotsky et al. (2018) and Del Vecchio et al. (2019). For statistical analysis, the Friedman non-parametric test was employed, following recommendations by Field (2013) for non-normally distributed data in repeated measures designs. Post-hoc pairwise comparisons were conducted using the Wilcoxon signed-rank test for multiple pairwise comparisons (Wasserman & Bockenholt, 1989).

Results and Discussions

A total of seven healthy male of age 27.5 years years (±12.5), of height 172.42 cm (±12.56)], weighing 152.16 lbs. (± 65.83) and with no history of MSDs, adequate sleep and having no allergies related to hydrogel were recruited. All the participants slept between 7-8 hours the previous day, which is the recommended sleep needed for adults to optimal cognitive functioning (Tai et al., 2022). None of the participants had any history of severe injury or musculoskeletal disorders.

Cumulative sEMG value for each session was determined and ranking of these muscles was done based on their cumulative sEMG value. Figure 3 shows an example of the cumulative values for all twelve muscles for one of the participants in one of the trials. The ranking for each muscle for every session of all seven participants was averaged to get the average ranking. Table 1 shows the average ranking of muscle activation during stooping tasks of 12 muscles examined during the experimental setup. Table 1 clearly shows that the most activated muscle is R. Biceps Femoris with an average ranking of 2.57 among all the participants. This was followed by L. Biceps Femoris with an average ranking of 2.82. These ranking values are higher compared to the muscles following them. The third and fourth ranked muscles were L. Rectus Abdominal (5.14) and R. Rectus Abdominal (5.29).

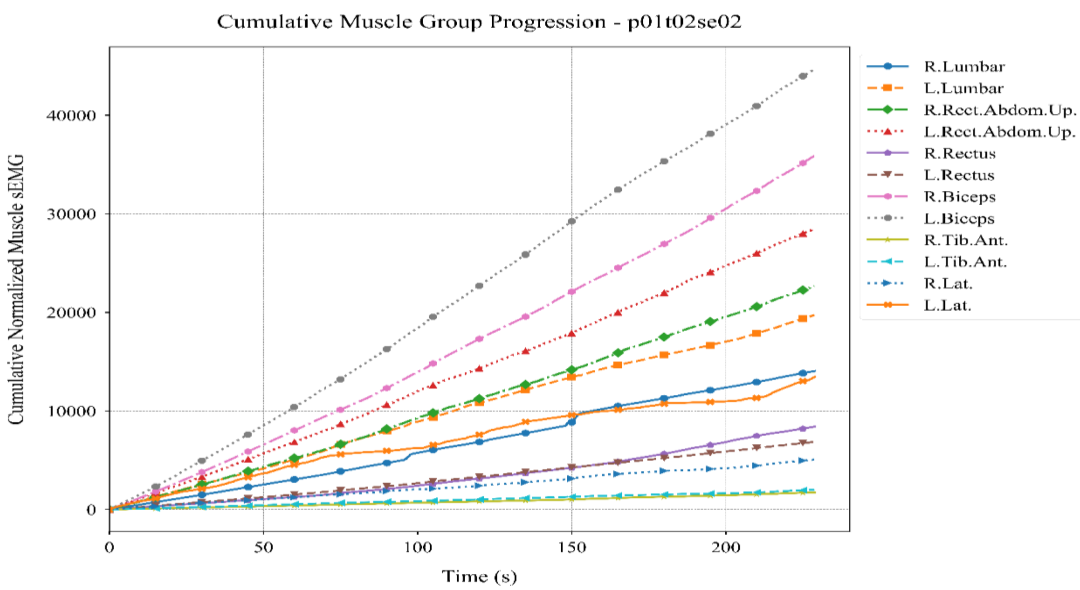

Figure 3. Graph of cumulative value of EMG signals over time for 12 muscles

R. Biceps Femoris and L. Biceps Femoris are the two most activated muscles. This implies that roofers rely more on these muscles for stooping purposes making them more susceptible to fatigue and injuries. Also, these muscles might be crucial for maintaining balance while in stooping posture on a sloped surface. Roofers need to properly stretch these body parts and need to be cautious if these parts of their body are not 100% fit. Frequent breaks should be encouraged to the workers to relax the muscles. Additionally, use of exoskeletal supports needs to be encouraged while performing stooping tasks in sloped surface for a sustained period.

Table 1. Overall Muscle Activation Ranking during Stooping Task

Muscle	**R. Lu**	**L. Lu**	**R. RA**	**L. RA**	**R. RF**	**L. RF**	**R. BF**	**L. BF**	**R. TA**	**L. TA**	**R. Ga**	**L. Ga**
Avg. Rank	5.75	6.04	5.29	5.14	9.61	9.39	2.57	2.82	9.46	8.54	7.79	5.61
O. Rank	6	7	4	3	12	10	1	2	11	9	8	5

Note: R. Lu – Right Lumbar | L. Lu- Left Lumbar | R. RA – Right Rectus Abdominal | L. RA- Left Rectus Abdominal | R. RF- Right Rectus Femoris | L. RF- Left Rectus Femoris | R. BF- Right Biceps Femoris | L. BF- Left Biceps Femoris | R. TA- Right Tibial Anterior | R. Ga- Right Gastrocnemius | L. Ga- Left Gastrocnemius | Avg. Rank – Average Rank | O. Rank- Overall Rank

The statistical significance of these rankings was checked using the non-parametric Friedman's Test with a null hypothesis that there is no significant difference between the ranking of these muscles. The Friedman's Test Statistic Value (F) is 143.15 with a p-value of $3.71 * 10^{-25}$. This shows that the observed difference in the ranking between the muscle groups is not random and there exists a strong statistical difference between the muscle rankings. The p-value is exceedingly small which helps in confidently rejecting the null-hypothesis. This implies that the ranked muscles (R. Biceps Femoris and L. Biceps Femoris) are more activated while performing stooping and roofers require to put more attention in terms of supports and rest as they are prone to fatigue, strain and injuries.

Table 2. Wilcoxon Pairwise Signed- Ranked Post Hoc Test for Muscle Ranking

	R. RA	**L. RA**	**R. BF**	**L. BF**
R. Lu	0.65	0.55	<0.01	<0.01
L. Lu	0.07	0.11	<0.01	<0.01
R. RA	1.00	0.29	<0.01	<0.01
L. RA	0.29	1.00	<0.01	0.02
L. RF	<0.01	<0.01	<0.01	<0.01
R. BF	<0.01	<0.01	1.00	0.96
L. BF	<0.01	0.02	0.96	1.00
R. TA	<0.01	<0.01	<0.01	<0.01
L. TA	<0.01	<0.01	<0.01	<0.01
R. Ga	<0.01	0.02	<0.01	<0.01
L. Ga	0.73	0.52	<0.01	<0.01

Note: R. Lu – Right Lumbar | L. Lu- Left Lumbar | R. RA – Right Rectus Abdominal | L. RA- Left Rectus Abdominal | R. RF- Right Rectus Femoris | L. RF- Left Rectus Femoris | R. BF- Right Biceps Femoris | L. BF- Left Biceps Femoris | R. TA- Right Tibial Anterior | R. Ga- Right Gastrocnemius | L. Ga- Left Gastrocnemius

Since the null-hypothesis was rejected, a Wilcoxon Pairwise signed-ranked post hoc test was performed within these muscles groups to find which specific pairs of muscle groups were significantly different from each other. Rankings of all 12 muscle groups were checked with the top 4 ranked using the Wilcoxon Pairwise signed-ranked post-hoc test to find specific differences between their ranks as shown in Table 2. R. Biceps and L. Biceps have a p-value of 0.95, which is significantly higher than 0.05. This shows that the ranking between R. Biceps and L. Biceps muscle groups do not have significant differences between them. This implies that both Biceps muscles are highly activated and needs proper attention while performing stooping posture. The intervention techniques need to be such that both R. Biceps Femoris and L. Biceps Femoris are relaxed or provided supported to. Recovery of these muscles need to be specifically taken care of during stooping posture in sloped surfaces.

However, the top two most activated muscle groups have significant differences compared to the other 10 muscle groups with the closest p-value being 0.02 which is lower than our level of significance 0.05 indicating that these two muscles were the most activated muscle groups. This further highlights the need to take proper care of Biceps muscles while stooping in sloped surface.

Conversely, the third and fourth most activated muscles L. Rectus Abdominis and R. Rectus Abdominis have p-values 0.52 and 0.72 in relation to L. Lateral Anterior. These values are significantly higher than the level of significance and hence indicate that the ranking between these muscle groups do not have significant differences. The results suggest that these muscles are activated in a balanced way and recovery for these muscles can be evenly distributed for these muscles.

Limitation

While in real life scenarios the slope may vary from house to house, this study results are from 30-degree slope only. Although some participants in this study had experience with construction and some had no experience at all, none of the participants had performed roofing tasks before. It might be possible that professional roofers might use their experience and expertise to adopt posture such that they optimize the muscle activation and muscle load. However, this study intended to identify the muscle activation of individuals newly exposed to stooping posture in a sloped surface, so they could be properly oriented about the muscle usage and take necessary intervention methods while performing such tasks.

Conclusion and Further Research

The study provides valuable insights on muscle activation patterns during stooping posture on a 30-degree sloped surface, a posture frequently encountered by roofers. The results show that Right and Left Biceps Femoris muscles were the highest ranked in activation during this task. This indicates that muscles bear a significant portion of workload while a person is working in this posture. The statistical significance of their activation levels compared to other muscles suggests a consistent pattern of strain in the lower extremities when working on sloped surfaces in a stooped posture. Repetitive strain on these muscles can lead to muscle fatigue, ultimately contributing to a higher incidence of WMSDs amongst roofers. Thus, ergonomic interventions such as external exoskeletal supports, task rotations are suggested to help alleviate the strain on the Biceps Femoris. Alongside, proper warmup related to specific muscle can help prepare the muscle for strain during the tasks which reduces the risk of long-term injury.

These results are important step forward towards determining muscle fatigue focusing on specific muscle groups. This will help in designing safer working conditions for roofers while reducing the physical strain related to awkward posture on sloped surface. Moreover, this research can be the steppingstone toward determining the best practice for specific construction activities. Further studies could investigate muscle activation across other common awkward postures for roofers to identify specific muscles groups susceptible to WMSDs at varying conditions. Additionally, the effectiveness of use of ergonomic aids such as supportive exoskeletons in reducing muscle load and activation and improving posture stability can be studied.

Acknowledgement

The authors would like to acknowledge all the participants who participated in this study and the instructors and professionals who administered the survey. The authors would also like to acknowledge the use of ChatGPT-4.0 and Grammarly in language assistance and checking grammar of this paper. ChatGPT-4.0 was also used for coding assistance for data analysis.

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