Journal of Engineering, Project, and Production Management
2025, 15(5), 2025-183

Comparative Ergonomic Analysis of Construction Students' Postures During Hands-on Training Activities

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Project Management
Received February 19, 2025; revised June 17, 2025; August 25, 2025; accepted August 25, 2025
Available online November 25, 2025

Abstract: Construction programs utilize a variety of delivery methods for content transfer. The type and format of each method entail advantages and disadvantages and are typically selected based on the nature of the content and available resources. Hands-on training is a favored method in construction education, as it provides various learning opportunities for students to engage in situations similar to real-world scenarios. Despite the favorable attitude among students, hands-on activities pose challenges and risks for administration and class management. Students' safety and health are among the challenges that instructors of project-based courses are continuously cognizant of and should plan for. Any hazardous activity throughout the training process may put students' short- or long-term health at risk. The two first-year studios in the construction program at Mississippi State University offer students rich hands-on activities in which they design and build modular houses. The main objective of this study was to evaluate the ergonomic posture of students during their physical activities and compare safe behavioral postures between genders. To reach this objective, a study was conducted in the summer and fall of 2024 in which a series of videos and pictures were recorded and analyzed using specialized software. The outcomes of the analyses were used to compare the safe posture and behaviors of construction students in male and female categories. The results indicated that both genders exhibited unsafe and hazardous postures in selected activities, despite differences in the safe status of body parts. The findings of this study help construction instructors and administrators to design and develop modules and guidelines for hands-on activities to ensure the health and well-being of current students and future professionals in the field of construction.

Keywords: Posture, safety, ergonomic status, musculoskeletal disorders.

DOI 10.32738/JEPPM-2025-183

1. Introduction

Construction programs hold a unique position in higher education due to their diverse learning methods. While theoretical knowledge is often imparted through lecture-based courses, many programs incorporate hands-on environments where students apply their knowledge through practical activities. These courses typically follow a lecture-lab format, with lectures delivered in traditional classrooms and practical application taking place in corresponding labs where students experiment, model, or create samples. The studio-based model, particularly in construction, is a distinct learning approach adopted by several institutions. Construction studios provide students with extended periods for physical and hands-on work, as the studio format integrates lecture and lab components.

The construction studios A and B within the Building Construction Science program at Mississippi State University encompass the design-build process of modular houses, integrating construction topics like construction drawing, safety, and materials and methods. Students commence building modular houses upon completion and finalization of the design phase. This construction process is a collaborative effort supervised by instructors and technicians. Prior to construction, students participate in training sessions to learn the correct usage of various construction equipment and tools. Furthermore, safety training is provided to ensure students are aware of potential risks and hazards during the construction phase. However, despite these training modules, formal instruction on ergonomic practices or safe execution of construction activities is lacking. Although various confounding factors such as time pressure, tool availability, individual cognitive differences may be involved in students' behaviors and perceptions, the lack of ergonomic knowledge and experience is highlighted.

Observations of student performance revealed deviations from recommended practices. This identified gap prompted the development of a study to investigate students' understanding of musculoskeletal disorders and analyze their postures during activities using recorded videos. The investigation of associations between several variables and students' performance may reveal the next layers of influencers. These variables include demographic and construction experience factors such as prior experience, previous courses, age, and gender. For example, previous construction experience may affect students' perceptions. The role of gender in such exploration is not sufficiently explored. This paper presents a segment of this study, focusing on gender-based comparisons of student performance in selected construction activities. The analysis of video data compares similarities and differences in the safety levels of male and female students' performance. The findings will assist construction scholars and instructors in designing training modules that emphasize safe postures for students. Additionally, these findings will enable construction educators to consider musculoskeletal disorder issues when designing hands-on activities for various construction classes.

2. Background

Musculoskeletal disorders (MSDs) are among the most common injuries in the world. To understand the effect of Musculoskeletal disorders, it is necessary to know what part of the body it involves. MSDs affect the performance of the locomotor system as well as the muscles, bones and joints in the human body. MSDs can vary widely and are also known by more common names such as osteoporosis, gout, arthritis, back pain and the like. These disorders affect millions of people around the world and are the subject of many research studies. This paper will serve as a literature review on what musculoskeletal disorders are, their risk factors and impacts on people as well as prevention and intervention strategies.

As of 2022, around 1.71 billion people suffer from musculoskeletal conditions around the world (Musculoskeletal Health, 2022). These conditions can prevent someone from doing their job or even lead to a permanent disability. MSDs are common across all kinds of industries and take a large toll on someone whether they are in an office or out working with their hands. Work-related musculoskeletal conditions are currently the primary cause for non-fatal injuries in construction (Wang et al., 2015). While there are many different types of Musculoskeletal disorders, there are some that seem to be in everyday life for most people. Two of the most common are classified as carpal tunnel syndrome and lower back pain. Carpal Tunnel Syndrome (CTS) is the most common peripheral nerve entrapment syndrome, and it is seen quite often in working adults. If not kept in check, CTS can impact the use of the wrist and fingers. As of 2015, CTS is seen in ninety-nine out of every one hundred thousand adults (Newington et al., 2015). While extremely prevalent, CTS can be prevented and treated as long as workers are conscious of their health. Current recommendations in the U.K. can range from 1-2 weeks all the way to 6-10 weeks. This time off can be extremely impactful on workers as well as their companies. While CTS is often seen in working age adults, lower back pain seems to be just as prominent. A global review was conducted in 2012 looking into the amount of backpain among adults and the results showed a lifetime prevalence of 39.9% among adults (Manchikanti et al., 2014). This is an alarmingly high percentage when the world's population is taken into account. Due to this, there has been a large amount of research done on the causes and risk factors that are causing these Musculoskeletal disorders.

With the number of MSDs present in the world today, it begs the question of what the causes of this are. There are numerous causes, but research has indicated the more prominent ones. An example of this would be occupational hazards. There are occupational hazards at work that can elevate a person's risk of getting an MSD and even cause them to reaggravate an old injury (Macdonald, 2015). These hazards can manifest in multiple ways and are seen across many different industries. Working in an awkward position or holding a tool that vibrates are just two examples of these hazards in a physical manner (Madan, 2015). Occupational hazards can also be organizational. This means that working night shifts and having high workloads can be detrimental to workers and be a factor in having a musculoskeletal disorder (Macdonald, 2015). This is because the strain on the mind can translate to the body through stress, lack of sleep, depression, etc. These can lead to making mistakes at work or working in a way that puts your body in danger. There has also been research into factors affecting MSDs that are seen outside of work. An example of this is that women experience MSDs more often due to them handling the household chores more often than men (Bevan, 2015). In other words, the strain on the body during cleaning at home can contribute to MSDs. Finally, there are individual factors that can increase workers' likelihood of getting MSDs. A prominent example of this is the workers' age. A study in 2011 looked at workers in the U.K. that were above 50 and compared them to workers that were 25 and younger. Evidence showed that the workers that were 50 and older showed a higher likelihood of getting MSDs (Okunribido et al., 2011). While the causes of MSDs are very important to identify, it is also important to look at the impact they have on workers.

Musculoskeletal disorders can debilitate and affect a person in many ways. This is due to MSDs' ability to inflict physical, mental and economic damage on an individual as well as an industry. The physical damage that impacts people is very prominent in the construction industry. In 2012, a study issued a questionnaire to 132 construction workers that asked them how they were affected by musculoskeletal disorders. The results showed that workers who had MSDs reported 39% more days where their health was affected in a month than those unaffected (Valsangkar and Surendranath, 2012). This is a large gap that shows just how much construction workers are affected. Another study in 2020 investigated veterans with MSDs and how it was affecting them. Out of the veterans they conducted the study on, 72% were overweight or obese and the average age was 59.4 years old (Higgins et al., 2020). This suggests that musculoskeletal disorders are a large contributor to making people that have them obese. Research also showed that there was a relationship between having a higher BMI and reporting more pain. While physical strains like these are a large burden, MSDs have also been shown to carry a psychological burden as well. The same study mentioned above about the construction workers showed evidence of this. The study reported that workers with MSDs had 20% more days where their mental health was affected than those without them. Also, there was almost no change between activity limitation between the group with MSDs and the group without (Valsangkar and Surendranath, 2012). So, while workers with MSD were reported more days where they were affected mentally and physically, they still worked nearly the same amount. While the construction industry is heavily affected by

MSDs, it is not the only industry dealing with corresponding issues. Other industries, with similar nature of work, are affected by MSDs too. For instance, research indicates that farmers are experiencing many of the same burdens. In 2018, farmers from a village from the Sangli district in India were studied to determine the prevalence of MSDs among them as well as their impacts on the farmers. Among 1150 farmers, 964 (83.8%) had some form of a musculoskeletal disorder. Furthermore, a total of 763 farmers needed medication to get relief from their pain (Patil et al., 2018). These farmers had to get medical consultation and then get medicine to get relief from their MSDs. Those services cost money for the farmers, their insurance companies, doctors and consumers of the farmers' products. To restate, MSDs are not only affecting individuals. They are affecting entire industries. When looking at the United States, this is apparent. In 2007, the direct costs of musculoskeletal disorders totaled around $1.5 billion, and the indirect costs were $1.1 billion (Bhattacharya, 2014). This massive amount of money shows just how much MSDs can affect an industry economically. Due to this, prevention and intervention strategies are supremely important to protect workers and economies.

The prevention and intervention of MSDs are becoming more important every day. The global workforce continues to grow, and this means more people are exposed to musculoskeletal disorders in an occupational setting. A study in 2020 researched prevention strategies for MSDs in the workplace and found that there is limited action taking place to prevent MSDs occurring at work. Due to this, the study found that a key step in prevention is to have a safe and healthy workplace for employees (Crawford et al., 2020). Being able to have a safe and protected space for employees to work in is important so that the employer can build off of that to fight MSDs. The next important step in preventing musculoskeletal disorders is exercise. According to Sunstrup et al. (2020), there are studies that show physical exercise in the workplace can help those with upper limb, neck or back conditions. In addition to physical exercise, other research suggests that physician recommendations and a change in lifestyle can also help people with MSDs. Some leading risk factors for MSDs are a lack of activity, bad diet and obesity. Research shows that physicians are recommending changes in lifestyle to combat these risk factors. Examples of these changes in lifestyle are implementing a diet and entering a weight loss program (Chen et al., 2022). This can help people with MSDs reduce the strain on their bodies and begin a road to recovery. After these steps have been introduced, there is another very important assignment that companies need to do. They need to regularly evaluate their staff and foster continuous improvement (Middlesworth, 2018). This enables a company to know how their employees are doing often and be able to respond to problems before they arise.

Musculoskeletal disorders continue to be a significant problem for many people and industries alike. These disorders affect people physically, mentally and economically, especially in fields that are physically demanding such as farming and construction. According to various studies, the prevalence of MSDs elevates the need for prevention and intervention strategies. By dealing with occupational hazards, promoting ergonomic practices and making lifestyle changes, people and industries can avoid some of the impacts that come with MSDs.

3. Methodology

The main objective of this research was to evaluate to what extent, students' performance in training processes in a construction course with physical activities were attentive and ergonomically safe. Specifically, this paper aimed to explore similarities and differences between female and male students while performing various construction activities. To define this experiment, a set of activities in a studio environment with hands-on activities was specified. These activities were certain construction activities such as framing, welding, and finishing that students, as future professionals, were required to do to practice and foster their knowledge. One of the assumptions in this study was that students will likely perform construction tasks similarly in other courses as well in their professional careers. While this assumption was not in impacting factor in the scope of this study and therefore not necessary to consider, in a larger scale any safe or unsafe behaviors or actions could continue and lead to further health issues. Thus, diagnoses and improvements in the current setting will help students to rectify unsafe postures and actions.

After defining the scope, objectives, and structure of the study, prior studies and literature were reviewed, which resulted in finalized study structure. In the next step, the study was presented to the XXX (deidentified) University's institutional review board for their review and evaluation, and their approval was obtained (IRB protocol-24-323). In the next step, construction activities in these training studios were determined to observe and track. In addition to regular fall/spring layout, the training studios were typically offered in a condensed delivery mode in summer. The sample size for this phase of the study included 21 male and 3 female students. These students were divided into different groups and each group comprised a combination of male and female students. A collection of videos was recorded during class time for various activities including both genders. The ergonomic assessment process involved analyzing video footage using Snapshot Ergonomics, a tool offered by VelocityEHS. Snapshot Ergonomics offers a faster, more efficient alternative to traditional ergonomic evaluation methods like prolonged observation or motion-tracking devices. This software enables quick, moment-specific observations, typically through photos or video clips, to assess individuals' postures and identify potential ergonomic hazards in particular scenarios. Snapshot Ergonomics facilitates swift evaluation of possible musculoskeletal concerns without requiring prolonged observation periods or sophisticated motion tracking equipment (Zargarzadeh et al., 2024). This approach allows for efficient identification of ergonomic risks based on single-point-in-time observations. Snapshot Ergonomics provides visual assessment which mainly relies on visual observation of an individual's posture. It produces a rapid analysis which helps to identify high-risk postures without requiring extensive data collection. It also utilizes computer vision and AI to calculate joint angles and ergonomic risk scores. The outputs of Snapshot Ergonomics analysis are in various form of risk assessments including color-coded risk scoring for quick prioritization of ergonomic issues, detailed body segment analysis, and AI-based musculoskeletal disorder (MSD) risk analysis. When these outputs were obtained from recorded videos, gender-based comparative analyses were conducted to identify similarities and differences between the risk assessment of female and male students' performance. The detailed results of these comparisons for selected activities are provided in the Results section.

Fig 1. Construction students' hands-on activities

4. Results

The current study included recorded work postures of students in varied positions or situations. To compare the male and female groups, recorded videos were classified based on the students' gender and type of activities. In the next step, videos from both gender in similar positions were selected and analyzed. This paper presents the analysis of postures and interactions for three types of activities including finishing, framing, and welding. These activities were selected due to sufficiency of videos for both genders in similar positions. While the construction process included other main activities, these three types were chosen to represent activities that both genders actively participated in. The recorded videos then were imported and analyzed in the software. The output of each video was a graph showing the safety status during the activities, categorized in three colors. These categories included green (safe situation), yellow (cautious situation) and red (hazardous situation). In addition, the output included an analysis for body parts, including full body, neck, back, right shoulder, right elbow, right knee, left shoulder, left elbow, and left knee. Fig. 2 shows an example of the output for two framing videos (male and female students).

Fig. 2. General output of analysis

Framing was the first type of activity analyzed. To accomplish the framing activity, students performed in various situations at different heights and sides of the building. Various videos were recorded and utilized in the analysis system. Then, the safety status of female and male students was analyzed for different body parts, and colored bar charts were produced. The body part comparison of the two categories, as shown in Fig. 3, indicates similarities and differences between the two categories.

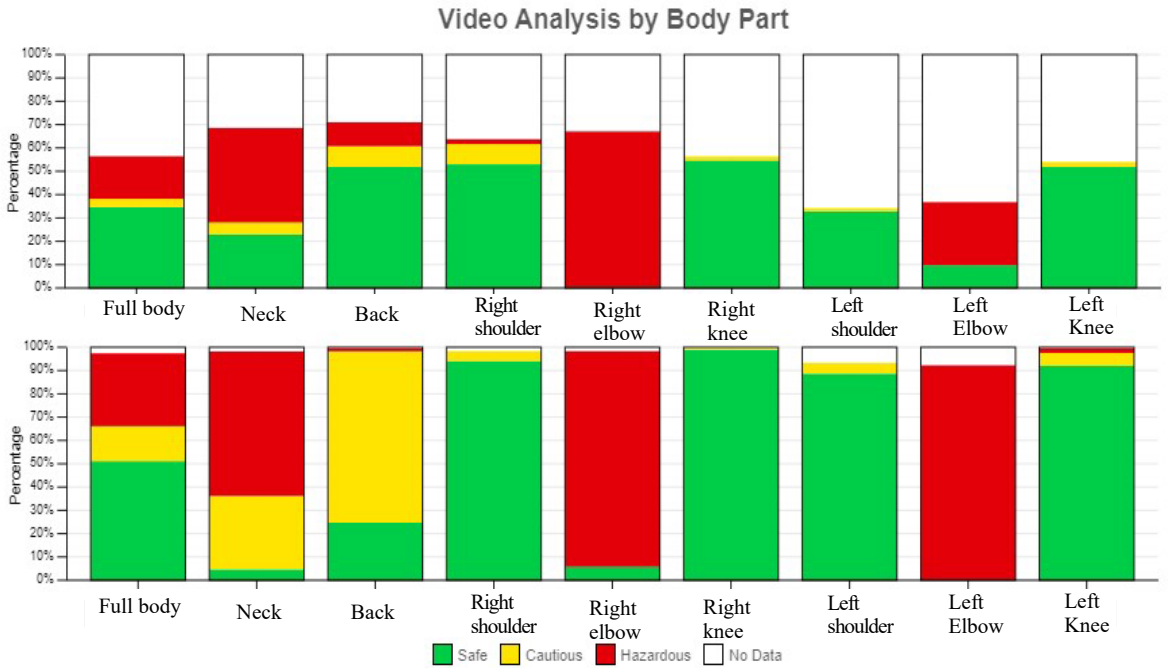

Fig. 3. Analysis output for a framing activity in female (top) and male (bottom) students

The overall comparison of the two categories shows that the area of red sections for the male category is higher than that of the female category. Similarly, the yellow area (cautious areas) in the male category is higher too. Both genders have most of their "neck" bars unsafe (i.e., red or yellow). In addition, both sides' elbows in both genders are mainly in red, which indicates both genders similarly put their elbows in unsafe situations. In addition, the "back" positions are generally in an unsafe situation, with the fact that the unsafe area (red and yellow) is considerably larger in the male category. However, as shown in Fig. 3, "shoulders" and "knees" are relatively in safe positions.

The next type of activity was welding in which students were required to work on a frame for light portable foundations of modular houses. Although the total time spent for this activity was shorter compared to other activities, students were required to complete a safety training and a technical session. Similar to other activities, students' performance during the welding activity was recorded, which was later used as inputs to the analytical software. The outputs of the software were categorized based on gender, as shown in Fig. 4.

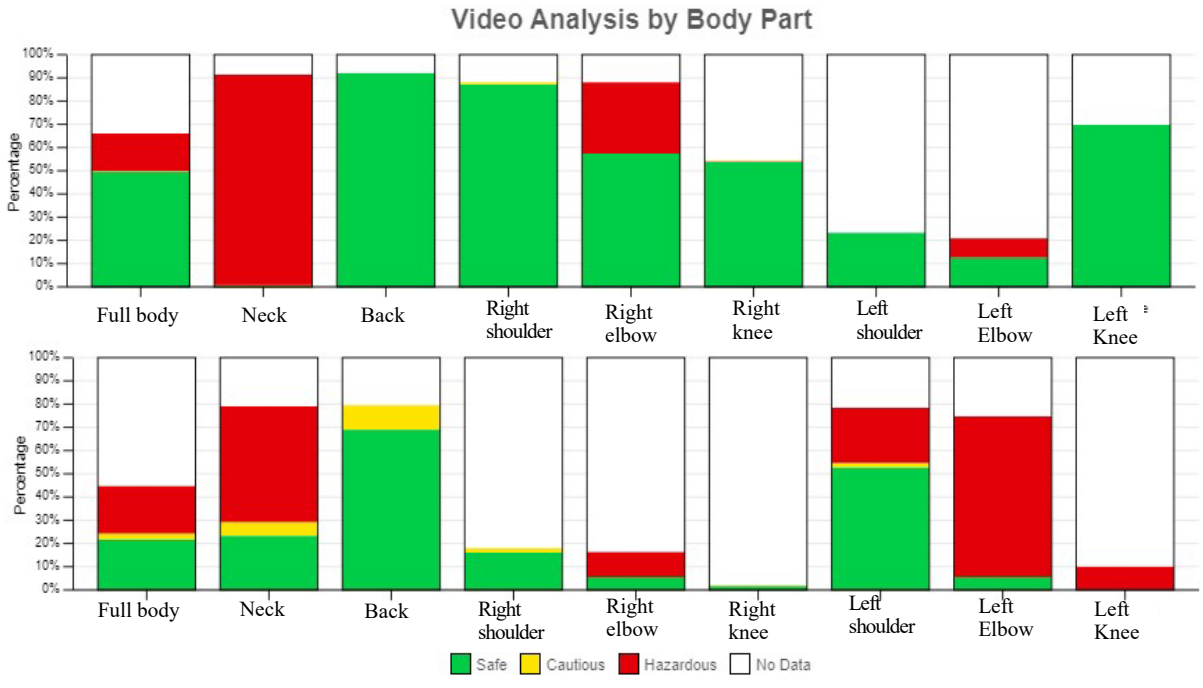

Fig. 4. Analysis output for a welding activity in female (top) and male (bottom) students

The comparison of gender-based outputs indicates similarities and differences in male and female categories. In general, the ratio of unsafe conditions to the safe ones (red/yellow to green) is lower than in other activities. Similar to other activities, the status of "neck" is largely unsafe, which requires particular attention. The "full body" is also in a mixed situation in both categories. Similarly, both genders show a similar pattern in both elbows; however, the left elbow in the male category considerably indicates an unsafe situation. In contrast, the back and knees are generally in safe positions. In general, a higher level of similarities between male and female students in welding is observable.

The next type of activity selected for analysis was finishing. In this activity, students were required to install finishes for their modular houses. Compared to the other two categories discussed previously, finishing comprised more sub-activities; however, the poses and interactions of these sub-activities were generally similar. Videos were captured and imported into the analysis software to assess the safety status of students' activities. The results of the comparative analysis are shown in Fig. 5.

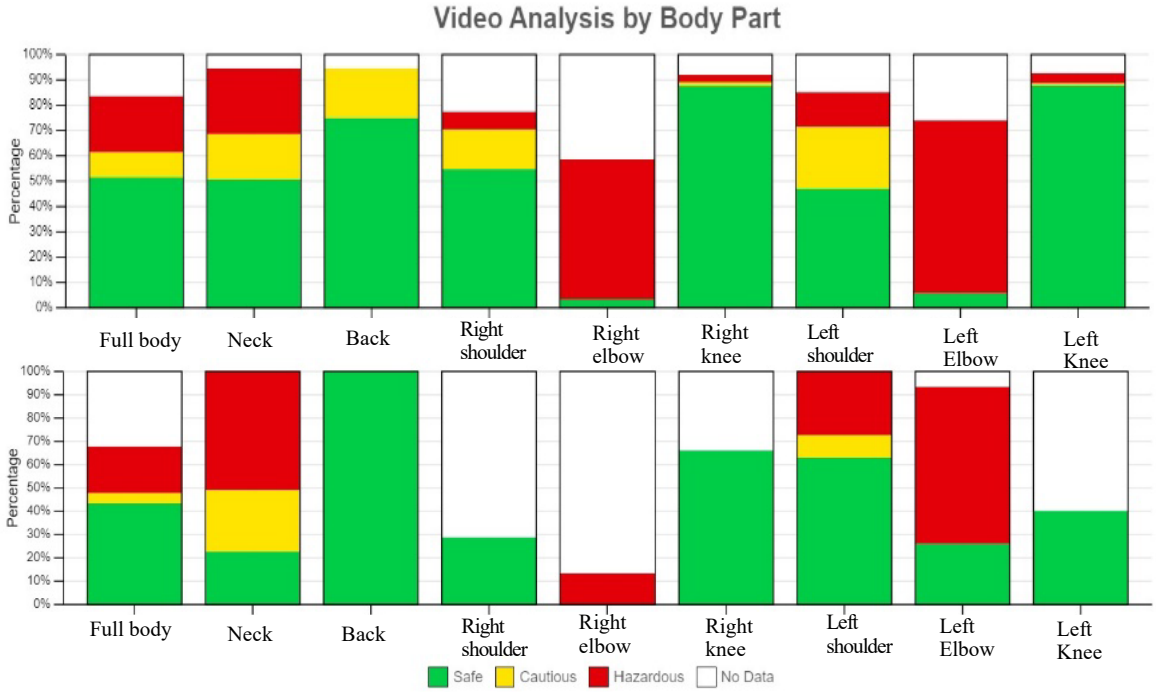

Fig. 5. Analysis output for a finishing activity in female (top) and male (bottom) students

The comparisons of body parts in finishing activities follow the trends discussed in welding. The full body status in both genders is a combination of safe, cautious, and hazardous. In addition, the neck and right shoulder in both genders have a mixed status as well. The back status in the female category was a combination of safe and hazardous, while it was completely safe in the male category. Similarly, both genders exhibited a hazardous status in both elbows. Also, both knees were generally in the green area in both genders.

5. Discussion

The analysis of student postures during various construction activities reveals several important insights into the safety status of different body parts across genders and activities. These findings have significant implications for improving safety practices and ergonomics in construction education and training.

- Full Body Status: The general mixed status observed for the full body across all activities and genders indicates that students are exposed to a combination of safe, cautious, and hazardous positions throughout their work. This variability suggests that while some aspects of their overall posture may be in a relatively safe status, there are still areas of concern that fall in the unsafe domain and therefore require additional scrutiny.

- Elbow and Knee Status: A consistent pattern emerged regarding the status of elbows and knees. The general hazardous status for elbows in all three activities (framing, welding, and finishing) for both genders is particularly concerning. This suggests that current work practices may be placing excessive strain on the elbow joints, potentially leading to musculoskeletal disorders over time. In contrast, the generally safe status observed for knees in both genders across activities is a positive finding, indicating that lower body positioning is relatively well-maintained.

- Back and Neck Concerns: The analysis revealed that back status might be unsafe, as observed in the framing activity. This is a critical area of concern, as back injuries are among the most common and debilitating musculoskeletal disorders in the construction industry. Additionally, the neck consistently showed unsafe positioning across activities and genders, highlighting another area requiring immediate attention.

- Gender Differences: It is noteworthy that different activities showed varying patterns between genders, making it difficult to conclude that one gender consistently performed safer than the other. This finding underscores the importance of individualized ergonomic assessments and tailored safety training rather than gender-based generalizations.

- Critical Areas for Intervention: The presence of body parts that are entirely or vastly in the red zone indicates areas that require careful attention and correction. These high-risk postures, if left unaddressed, could lead to acute injuries or chronic musculoskeletal conditions. Identifying these specific problem areas allows for targeted interventions and ergonomic improvements

The review of similarities and differences between the two genders lays a foundation for several recommendations. These suggestions can improve students understanding of correction posture and decrease musculoskeletal disorders (MSDs).

- Education and Monitoring: There is a clear need to educate students on proper body postures and ergonomic principles. This education should be followed by consistent monitoring to verify that safe practices are being implemented. Construction Equipment and Methods, Construction Safety, and Human Factors in Construction are examples of courses in which relevant educational materials can be provided.

- Activity Design: Instructors should carefully design activities with consideration for location, situation, and height to minimize unsafe postures. This may involve redesigning workstations, adjusting work heights, or introducing ergonomic tools and equipment to support safer body mechanics. Applicable guidelines can be provided to students prior to modules or main activities.

- Targeted Interventions: Special attention should be given to improving elbow and neck postures across all activities, as these areas consistently showed hazardous positioning. This could involve specific exercises, stretches, or modifications to work techniques.

- Gender-Specific Considerations: While gender-based generalizations should be avoided, instructors should be aware of potential differences in posture and technique between male and female students. This awareness can inform more personalized guidance and support. More gender-focused studies may reveal additional differences and similarities among students performing their assigned tasks.

By implementing these recommendations, construction education programs can improve student safety, reduce the risk of musculoskeletal disorders, and better prepare students for the physical demands of their future careers in the construction industry. Continuous assessment and refinement of these practices will be essential to ensure long-term effectiveness and adaptation to evolving construction techniques and technologies.

It should be noted that each output is the product of a short-period observation, which to some extent captures a sustained posture. However, the objective in the proposed approach is to collect a set of observations from Different Students, in Locations, at Different Times for a certain activity. As a result, the conclusion drawn from these possibilities provides a consistent and reliable finding. In Addition, repeated measures in different projects with diverse groups of students enhance the reliability of the analysis.

6. Conclusion

This study examined the ergonomic postures of construction students during hands-on training activities, comparing male and female students across various tasks. The analysis revealed several key findings that have important implications for construction education and safety practices. Overall, the results indicated a mixed status for full body postures across both genders and all activities. This suggests that while some aspects of students' postures are acceptable, there are still significant areas of concern that require attention. Particularly noteworthy was the consistently hazardous status observed for elbows in framing, welding, and finishing activities for both male and female students. This finding highlights a critical area for intervention to prevent potential long-term musculoskeletal disorders. In contrast, knee postures were generally found to be safe across genders and activities, indicating that lower body positioning is relatively well-maintained. However, back and neck postures showed concerning trends, with unsafe positions observed particularly during framing activities. These areas require immediate attention given the prevalence and severity of back and neck injuries in the construction industry. Based on these findings, several recommendations have been proposed, including enhanced education on proper body postures, careful design of training activities to minimize unsafe postures, targeted interventions for high-risk body parts, and consideration of gender-specific factors in training and guidance. It should be noted that this study was a pilot exploratory one and further detailed designs will be required for high reliability; therefore, the generalization of findings is not warranted. Since there were a relatively low number of students, especially female ones, in the target course, collecting a homogeneous set of videos, with comparable situations between male and female students was difficult and therefore the study was not able to perform statistical significance testing comparisons. Additional experiments may include higher number of participants, especially female students, in various activities and more frequent intervals. In addition, obtaining the data from different cohorts of students will increase the reliability of findings. Overall, this study provides valuable insights into the ergonomic challenges faced by construction students during hands-on training. By implementing the recommended strategies, construction education programs can significantly improve student safety, reduce the risk of musculoskeletal disorders, and better prepare students for the physical demands of their future careers in the construction industry. Future research should focus on longitudinal studies to assess the long-term impact of these interventions and explore additional strategies to enhance ergonomic safety in construction education and practice.

Author Contributions

Saeed Rokooei contributes to conceptualization, methodology, background review, analysis, data analysis, draft preparation, manuscript editing, and visualization. Mohsen Garshasby contributes to conceptualization, methodology, software, validation, data collection, draft preparation, and funding acquisition. All authors have read and agreed with the manuscript before its submission and publication.

Funding

This study was supported by internal funding provided by the Department of Building Construction Science at Mississippi State University.

Institutional Review Board Statement

This study was approved by the Institutional Review Board (IRB) at Mississippi State University (Protocol #IRB-24-323).

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Mohsen Garshasby is an Assistant Professor of Building Construction Science at Mississippi State University. His research focuses on construction safety education, with a particular emphasis on musculoskeletal disorder (MSD) risks, ergonomics, and workforce training in physically demanding construction environments. He leads applied research projects that assess ergonomic hazards in student learning settings and field-based construction tasks, integrating safety science into undergraduate construction curricula. His work explores the translation of evidence-based safety practices into academic and industry training, aiming to strengthen the foundational safety knowledge of future construction professionals.