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Exploring Vision-Based Technologies for Ergonomic Training in Construction Education

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Abstract - Musculoskeletal disorders (MSDs) are a critical concern in construction, frequently caused by repetitive motions, awkward postures, and heavy lifting. These risks are prevalent not only in industry but also in educational settings where students engage in hands-on tasks that mirror real-world conditions. This study investigates the integration of vision-based technologies, specifically Snapshot Ergonomics, into construction education to assess and address ergonomic risks. Snapshot Ergonomics uses video-based motion capture, artificial intelligence (AI), and machine learning (ML) to classify postures as Safe, Cautious, or Hazardous. Three key fabrication activities – wood framing, steel welding, and cladding/finishing – were analyzed with a sample size of nine participants across distinct task variations. Results revealed that neck and elbow postures frequently exhibited hazardous positions, emphasizing the need for ergonomic interventions. This paper discusses the feasibility, scalability, and implications of these tools in improving safety education, ultimately fostering a proactive safety culture in construction.

***Keywords*:** Musculoskeletal Disorders, Construction, Ergonomic, Posture

1. Introduction

The construction industry, while recognized for its significant economic contributions, is also one of the most hazardous sectors due to the physically demanding nature of the work [1], [2], [3]. The repercussions of workplace injuries in this sector are substantial, with the combined cost of both fatal and non-fatal incidents exceeding $48 billion annually [4]. These economic impacts can adversely affect project outcomes, return on investment, and the financial stability of construction firms [5]. Among these injuries, work-related musculoskeletal disorders (WMSDs) -- referred to as MSDs in this context -- stand out due to their prevalence and impact.

MSDs are injuries or disorders that impact the muscles, joints, nerves, tendons, cartilage, and spinal discs. These conditions often arise from work-related activities, including sustained or awkward postures, overexertion from lifting and carrying heavy loads, repetitive tasks, and exposure to whole-body vibrations [6], [7]. MSDs account for approximately 33% of all work-related injuries and illnesses that lead to days away from work for recovery in the United States [5]. Early intervention through targeted training and education at the collegiate level offers a promising opportunity to address critical issues related to safety, ergonomics, and MSDs.

Despite the importance of early education, research on the standard ergonomic practices within construction education -- particularly in classroom and lab-based fabrication tasks -- remains limited. Therefore, this study aims to bridge the gap between theoretical ergonomics and practical applications within the construction education environment. By utilizing observation data via video recordings collected from students and analyzing the ergonomic risks faced by students in hands-on fabrication activities -- such as framing, welding, and cladding/finishing -- this research provides foundational insights for educators to implement effective ergonomic training and posture correction measures. Such proactive interventions are essential for instilling a safety-first mindset among future construction professionals, ultimately reducing MSDs and improving overall well-being within the industry.

2. Literature Review

Musculoskeletal disorders (MSDs) are a leading occupational health concern in the construction industry, with a significantly higher prevalence compared to other sectors [7]. The physically demanding nature of construction work -- such as heavy lifting, repetitive movements, and awkward postures -- places workers at substantial risk for MSDs [8]. The National Institute for Occupational Safety and Health (NIOSH) identifies MSDs as a primary cause of disability among construction workers, emphasizing the need for comprehensive risk mitigation measures [8].

Ergonomics plays a critical role in reducing these risks. Studies highlight that ergonomic interventions -- such as tool redesign, adjusted work areas, and improved work practices -- can significantly decrease musculoskeletal complaints [9]. Improved ergonomics not only reduce physical strain but also enhance productivity by lowering error rates and increasing efficiency [10] & [11]. Integrating ergonomic education into construction training is crucial for fostering a safety-oriented culture that prioritizes worker health.

Researchers and regulatory bodies have developed methods to assess and address MSD risks, including self-reported methods, observational assessments, vision-based approaches, and direct measurement techniques [5] & [7]. Observational methods, such as OWAS, PATH, RULA, and REBA, focus on evaluating posture, frequency, and severity of ergonomic risks [12], [13], [14], & [15]. However, self-reported and observational assessments methods face challenges such as reliance on experienced observers and potential bias, which in turn makes vision-based tools a promising alternative for scalable and objective assessments.

Recent advancements in vision-based ergonomic analysis tools, like Snapshot Ergonomics, offer a reliable means to evaluate worker postures. This software uses video-based motion capture, artificial intelligence (AI), and machine learning (ML) to generate 3D models of body movements, categorizing postures into Safe, Cautious, and Hazardous risk levels [16], [17], & [18]. By minimizing observer bias, these tools facilitate targeted ergonomic interventions in both professional and educational settings.

While substantial research addresses ergonomic risks in professional construction, limited studies explore their application in construction education. This study aims to fill this gap by employing vision-based analysis to evaluate ergonomic risks during student fabrication tasks, contributing valuable insights for educators and preparing students for safer practices in their professional careers.

3. Methodology

This study applied a vision-based approach to evaluate musculoskeletal disorder (MSD) risks among construction students during hands-on fabrication activities, including framing (wood), welding, and finishing (cladding and other tasks). Conducted in a project-based class simulating real-world construction conditions, this pilot study involved motion capture data from nine students. Several analysis outputs figures are provided in the paper. Institutional Review Board (IRB protocol-24-323) approval was secured, and participants provided informed consent. Video recordings captured students' postures and movements during tasks, enabling detailed ergonomic analysis using Snapshot Ergonomics software.

Snapshot Ergonomics utilized video-based motion capture with artificial intelligence (AI) and machine learning (ML) to generate three-dimensional (3D) models of body movements. The software categorized postures into Safe (green), Cautious (yellow), and Hazardous (red) risk levels for body parts such as the neck, back, shoulders, and elbows. Video footage was segmented to analyze key task sequences, identifying unsafe postures and transitions to hazardous positions. This approach minimized observer bias, providing consistent and objective assessments to inform ergonomic interventions and enhance student safety during construction training.

4. Results

As described in the previous sections, three major types of activities were selected. These types included framing, welding, and finishing. In each type, three different positions or situations were selected to improve the comprehensiveness of the activity analysis. Postures and interactions were then analyzed, and the outputs were produced in three different status categories of Safe (green), Cautious (yellow), and Hazardous (red). In addition, the outputs were rendered to specify the percentage of each safety status for various body parts, including full body, neck, back, right shoulder, right elbow, right knee, left shoulder, left elbow, and left knee. Figure 1 shows an example of output for a framing activity.

Fig. 1: Visual analysis for a framing activity

The observation of graphical elements in the output (i.e., line colors with angles, and colored areas on the bar charts) in the selected activity shows that the majority of positions had either a cautious or hazardous status for all body parts, except left shoulder and elbow. The overview of categorized graphical outputs and comparisons of positions in an activity reveal the intensity of safe/hazardous performance. Additionally, it shows the commonality of risks to body parts, as shown in Figures 2-4.

The first set of activities included the framing activity in which students needed to perform in different positions at different heights to perform framing-related tasks. The comparative analysis of risks to body parts for three individuals with different postures (Figure 2) indicates that right and left shoulders were generally in safe status, while right and left elbows were in hazardous positions. Another noticeable point is the status of the neck, which generally was in a hazardous position. Similarly, the back was also in an unsafe position, though with a lower risk intensity.

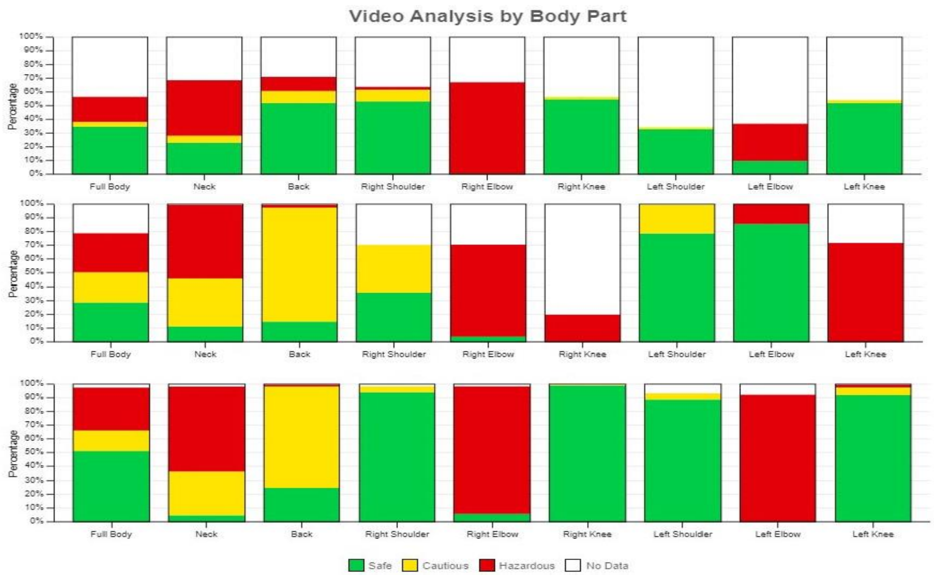

Fig. 2: Analysis output for a framing activity

The next set of activities included welding sub-activities in which students needed to work on a frame for the portable foundation of a modular building. The output of the posture analysis for three individuals is shown in Figure 3. The analysis of body parts shows a combination of safe, cautious, and hazardous positions for different postures. In general, the full body had a combination of safe and hazardous positions. Unlike other body parts, the neck was significantly in hazardous situations. The intensity of hazardous positions was even higher than in other activities. Back, right shoulder, right knee, left shoulder, and left knee were generally in safe positions with small deviations. However, elbows on both sides showed a risk-prone position as they had a notable portion of hazardous positions.

The third set of activities comprised tasks related to finishing. A similar output set for three safety statuses and risks to body parts was generated for three individuals with different positions, as shown in Figure 4. A similar trend is observable in finishing sub-activities outputs. The full body was a mixture of three risk statuses. The neck, with notable distinction, was in a hazardous position. Elbows were generally in cautious or hazardous positions, and other body parts generally had a safe status while cautious moments were detected as well. Another notable point in finishing outputs, compared to welding, was the presence of midpoints (yellow areas) in the continuum from safe to hazardous positions. In welding, safe positions could rapidly change to hazardous ones without these intermediate stages.

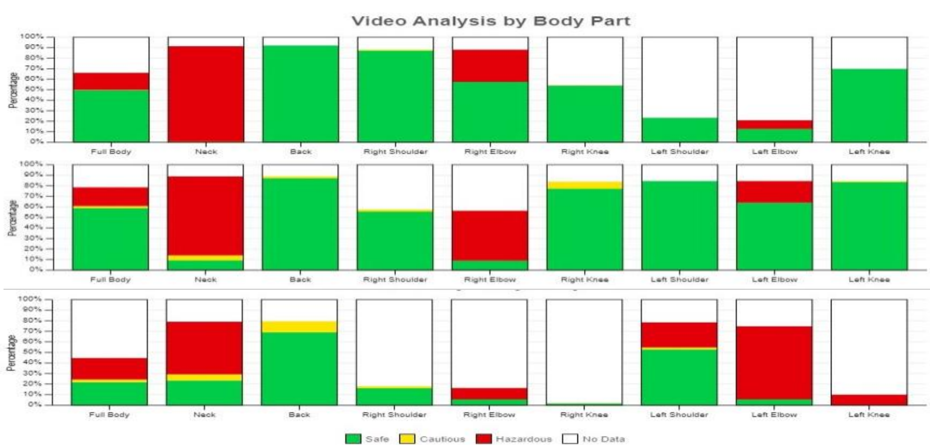

Fig. 3: Analysis output for a welding activity

In general neck and elbows appeared to be more prone to risks of poor posture in three types of activities.

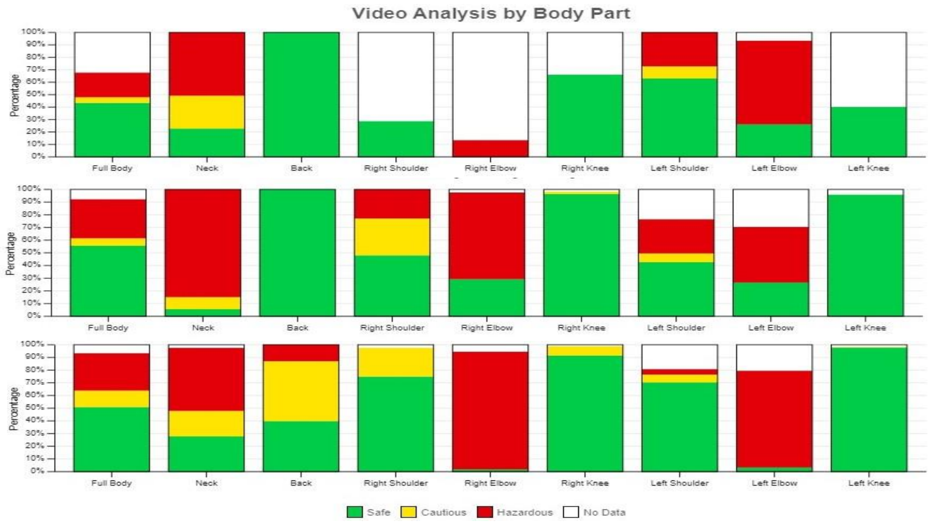

Fig. 4: Analysis output for a finishing activity

5. Discussion

The analysis of students' postures during their construction activities reveals several notable points that have significant implications for both education and future industry practices. Such analyses potentially have two substantial outcomes: first, they can help correct students' postures, which directly impact their health and wellbeing, and second, they prepare students as future construction leaders to effectively guide and inform construction workers about proper ergonomics while performing various tasks. While a comprehensive analysis of construction activities would require a large amount of data derived from a multitude of construction projects with different sizes, locations, types, uses, and delivery methods, this current pilot study provides valuable insights into safe procedures for students learning construction content. The results along with a lecture on ergonomic safe practices were shared with students upon the completion of preliminary analysis. The highlight critical areas of concern and opportunities for improvement in ergonomic practices within construction education and, by extension, the industry at large.

One striking observation is the consistent risk to the neck across all three types of activities examined: framing, welding, and finishing. In nearly all postures analyzed, the neck was predominantly in a hazardous position, indicating a critical area of concern for student safety and ergonomics during construction training. This finding underscores the need for targeted interventions and ergonomic solutions focused on neck positioning and support during various construction tasks. The prevalence of this issue across different activities suggests that it may be a systemic problem in construction work, possibly related to the nature of tasks that require looking down on or at awkward angles for extended periods.

Similarly, the analysis shows that risks to elbows are highly prevalent in all three types of activities. Both right and left elbows frequently exhibited cautious or hazardous positions, particularly during welding and finishing tasks. This consistent risk to elbow joints across different activities suggests a systemic issue in how students position their arms during construction work, potentially due to the nature of the tasks or the design of tools and workstations. The repetitive nature of many construction tasks, combined with the need to maintain specific arm positions for extended periods, may contribute to this elevated risk for elbow strain or injury.

Interestingly, framing activities, unlike welding and finishing, demonstrated a notably higher risk for the back. The comparative analysis revealed that during framing tasks, the back was often in unsafe positions, albeit with varying degrees of risk intensity. This unique risk profile for framing activities highlights the need for specific attention to back posture and support during these tasks, which may involve more bending, lifting, or awkward positioning compared to other activities. The dynamic nature of framing work, which often requires workers to maneuver in confined spaces or handle heavy materials, likely contributes to this increased risk for back strain.

The analysis of full body postures across all activities showed a mixture of safe, cautious, and hazardous positions. This variability in overall body positioning suggests that while certain body parts may be at higher risk, there are opportunities for students to adopt safer postures in some aspects of their work. The presence of safe positions, even in activities with high-risk elements, indicates potential for improvement through targeted training and ergonomic interventions. This finding is particularly encouraging as it suggests that with proper education and awareness, students can learn to maintain safer postures even during challenging tasks.

A significant finding from the analysis is that the angle of body parts has a substantial impact on the safe status of the activity. The graphical outputs clearly demonstrated how slight changes in joint angles could shift a position from safe to cautious or hazardous. This sensitivity to body part angles emphasizes the importance of precise positioning and the potential benefits of real- time feedback systems to help students maintain optimal postures during construction activities. The development of such feedback systems, perhaps utilizing wearable technology or augmented reality, could revolutionize ergonomic training in construction education and practice.

These findings collectively point to the need for a multifaceted approach to improving student safety and ergonomics in construction education. By addressing the specific risks identified for neck, elbows, and back, and by focusing on optimal full-body positioning, educators can enhance the learning environment while instilling good ergonomic practices that students can carry into their professional careers. This approach should include not only theoretical instruction but also practical training that allows students to develop muscle memory for safe postures and movements.

Furthermore, the insights gained from this analysis can inform the development of more ergonomic tools, workstations, and protective equipment tailored to the unique demands of different construction activities. For instance, neck support devices could be designed for tasks that require prolonged downward gaze, while elbow braces or ergonomic tool handles could help mitigate risks to the arms. For framing activities, the development of assistive devices or improved lifting techniques could help reduce the strain on workers' backs.

In addition to these physical solutions, the findings highlight the importance of incorporating regular breaks and stretching exercises into construction work routines. These practices can help alleviate the cumulative stress on high-risk body parts and promote overall musculoskeletal health among workers. Moreover, the study highlights the potential value of rotation systems that allow workers to switch between different tasks throughout the day, thereby distributing the physical strain across various muscle groups and reducing the risk of repetitive stress injuries.

The implications of this study extend beyond the immediate context of construction education. By instilling good ergonomic practices in students, the construction industry can potentially see a long-term reduction in work-related musculoskeletal disorders, leading to improved worker health, increased productivity, and reduced healthcare and workers' compensation costs. Additionally, as these students become future leaders in the construction industry, they will be better equipped to implement and enforce ergonomic practices on job sites, creating a positive cycle of improved safety and health awareness in the field. This pilot study provides a foundation for further research into ergonomics in construction education and practice. By continuing to prioritize and refine ergonomic practices in construction education, construction educators and professionals can work towards creating a safer, healthier, and more sustainable construction industry for future generations.

6. Conclusion

This study identified significant musculoskeletal disorder (MSD) risks among construction students performing fabrication tasks such as framing, welding, and finishing. Snapshot Ergonomics software provided objective assessments, highlighting key postural risks, particularly for the neck and elbows, which were frequently in hazardous positions. Framing tasks also showed notable back risks due to bending and lifting demands. Addressing these ergonomic challenges during training fosters a safety-oriented mindset in future construction professionals. Early exposure to ergonomic practices helps students adopt safer work habits, reducing MSD risks and improving workplace safety. By integrating ergonomic training and real-time feedback tools, construction education programs can create safer learning environments and prepare students to manage the industry's physical demands effectively.

Future research should expand on the findings of this study by including a larger and more diverse sample of participants to ensure generalizability across different demographics and construction tasks. Additionally, integrating real-time feedback systems, such as wearable sensors or augmented reality devices, could provide immediate corrective guidance to students, further enhancing their ergonomic awareness and posture. Another potential direction for future work involves developing targeted intervention programs based on the specific risk areas identified in this study -- such as the neck, elbows, and back.

These interventions could include ergonomic training modules, revised task workflows, or customized equipment to better support student posture during fabrication tasks. Collaboration with industry professionals to test and implement these solutions in real-world construction environments would also help bridge the gap between academic learning and industry practice, ultimately leading to a safer construction industry.

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