Effects of Drone Distraction on Roofing Sites: A Quantitative Assessment of Roofers' Balance During Critical Stooping Task

Mahfuza Maisha Mouri[1], Wei Han[2], Liqun Xu[2], Alireza Ghasemi[1], Wei-Yin Loh[3], Zhenhua Zhu[2], Fei Dai[1]

[1]Wadsworth Department of Civil and Environmental Engineering, West Virginia University, USA
[2]Department of Civil and Environmental Engineering, University of Wisconsin - Madison, USA
[3]Department of Statistics, University of Wisconsin - Madison, USA
mm00286@mix.wvu.edu, whan59@wisc.edu, liqun.xu@wisc.edu, ag00085@mix.wvu.edu, loh@stat.wisc.edu, zzhu286@wisc.edu, fei.dai@mail.wvu.edu

Abstract –

Roofers often work on sloped surfaces and in awkward postures, which increases their risk of falls and injuries. In recent years, drones have been increasingly used in construction, but their presence may distract workers. Such distractions can compromise balance, which is especially critical for roofers working in challenging conditions, where maintaining focus and precise postural control is essential to prevent slips or falls. This study investigated how drone proximity affects roofers' balance during a simulated shingle installation task. Twenty-five participants performed the task in stooping posture on a wooden roof platform with three slopes (0, 3/12, 6/12) under four drone conditions (no drone, 16 ft, 48 ft, 82 ft). Participants experienced virtual roofing environment using a virtual reality (VR) headset. Postural stability was measured using center of pressure (COP) trajectories recorded on a force plate and processed into a stability indicator, sway area, for analysis. Results indicated that the closest drone, at 16 ft, significantly increased distraction and reduced stability. The higher drone altitudes also produced statistically significant effects compared to the no-drone condition. These findings enhance understanding of how drone proximity affects roofers' balance and provide a foundation for developing improved safety protocols in roofing environments.

Keywords –

Drones; Roofers; Virtual reality; Safety; Stooping

1 Introduction

The roofing industry is one of the most hazardous sectors within the construction industry [1]. Roofers face a significantly higher risk, being approximately three times more likely than other construction workers to experience fatal injuries. [1]. Slips, trips, and balance loss are commonly reported as the main causes of roofing falls [2]. Operating on sloped and slippery surfaces requires careful balance control to avoid falls and ensure stability [1].

Roofers frequently work in uncomfortable positions, with stooping being one of the most common during shingle installation [3]. Stooping involves bending mainly at the waist with minimal knee flexion and feet flat on the surface. Performing tasks in this posture requires considerable coordination, strength, and flexibility [4]. The roofing work environment increases the risk of balance loss, as tasks require roofers to maintain precise control of their posture while effectively managing disturbances that could affect stability [5]. In such challenging environment, external disturbances such as drones may distract workers and cause loss of balance, which is particularly critical for roofers who work at height on sloped surfaces and already experience the highest injury rates from falls.

The growing use of drones in construction projects has attracted significant industry attention because of their potential to improve both efficiency and safety [6]. However, drone use also introduces new operational and safety risks that go beyond physical hazards such as collisions with workers, equipment, or site infrastructure [7]. Drones on construction sites can distract workers, particularly those working at heights, thereby increasing the risk of falls and other accidents [8]. Roofers are especially vulnerable to drone-induced distractions, as drones frequently operate above roofing areas. These distractions can cause roofers to lose balance on elevated and sloped surfaces, increasing the likelihood of slips, trips, and falls, which often result in serious injuries or fatalities. While many studies have examined drone-related safety risks, the specific impact of drone distractions on roofers' balance remains underexplored.

2 Literature Review

2.1 Use of Drones in Construction and Associated Safety Risks

Advances in technology and reductions in cost have made drones, also known as unmanned aerial vehicles (UAVs), widely accessible to both consumers and professionals [9]. In recent years, drones have gained popularity in the construction industry due to their numerous benefits [10]. They can be deployed throughout the entire project lifecycle, from pre-planning and design to construction, asset management, and facility operation. Drones have a wide range of applications in construction, including topographic mapping, site surveying, progress monitoring, equipment tracking, structural inspection, and safety monitoring [11]. Their ability to access areas that are difficult or hazardous to reach is particularly valuable for high structures such as roofs. Using drones for roof inspection allows for rapid, safe, and accurate assessment, improving efficiency, reducing costs, and enhancing roofer safety [9].

Despite the advantages of drone use, there is increasing concern that they may introduce additional safety risks and hazards on construction sites [12]. Drone-related safety risks include potential privacy violations from constant surveillance [13], loss of control, and distractions on construction sites [14]. Drone-generated noise and movement can disrupt workers' focus and reduce their concentration [14]. A survey of construction experts and professionals also identified multiple hazards associated with drone use, with distraction highlighted as a primary safety concern [15]. Roofers working at heights, who already face the highest fatality rates, are especially susceptible to these additional risks posed by drones [16].

Previous research on drone-related risks and hazards in construction has been largely qualitative, relying on surveys, expert opinions, and conceptual analyses. Quantitative studies on the impact of drone-induced distractions can provide concrete evidence to inform safe drone use on construction sites. Although some research has attempted to measure risks caused by drones [16, 17] there remains a lack of quantitative analysis specifically examining how drone induced distractions affect balance, a factor that is particularly critical for roofers working at height and in awkward, high-risk postures such as stooping.

2.2 Virtual Reality (VR)-Based Investigations of Drone Distraction

VR has been widely used across various domains to investigate the effects of drone-induced distractions. enables humans to immerse themselves in simulated environments, making it an ideal tool for studying how drones distract workers and affect their balance in a controlled and safe manner. For example, a VR-based driving simulator was used to study the impact of nearby drone flights, showing that drones can contribute to driver distraction and supporting a policy requiring drones to maintain at least a 25 feet distance from the edge of the roadway. Another study, also using a driving simulator, found that drones distracted drivers and caused dangerously prolonged glances away from the road [18]. In construction, VR has been used to simulate construction worksites for experiments assessing the impact of drone presence on workers' attention. Findings showed that drones could distract workers, particularly when operating at distances of 12 and 25 feet [19]. Another VR-based study examining drone distraction found that drones positioned at greater distances led to more frequent and prolonged visual fixations on the drones, highlighting their potential to divert construction workers' attention [20].

Most existing studies have focused on how drone presence diverts workers' attention from their tasks. However, they have not examined how this distraction impacts workers' postural control.

3 Problem Statement and Research Objective

Previous research has underscored the risks that drone-induced distractions pose to construction workers. Although various aspects of these distractions have been studied, there is a lack of systematic, quantitative investigation into their effects on postural stability, especially during prolonged tasks like shingle installation in a stooped position. This study aims to empirically assess the impact of drone presence at different distances on roofers' postural balance using VR.

4 Experiment Design

4.1 Participants

A total of 25 participants (16 males and 9 females) took part in the experiment. The study protocol was reviewed and approved by the West Virginia University Institutional Review Board (IRB). All participants were physically active young adults. Although they were not professional roofers, they had relevant internship or work experience in the construction industry.

4.2 Variables

The experiment involved three categories of variables. Controlled variables were held constant and included the drone's flight direction, speed, and sound. The dependent variable was the 95% confidence ellipse area of the center of pressure (COP) trajectory, which represents the smallest ellipse containing 95% of sway data and captures coupled variability in anteroposterior and mediolateral directions. This metric, which is called sway area, is less sensitive to transient outliers than peak-based measures and is commonly used to characterize overall postural stability. Prior studies have shown that larger sway area is directly associated with reduced postural control and increased fall risk [21]. The independent variables consisted of roof slope (0 pitch, 3/12 pitch, and 6/12 pitch) and drone flight height above the participants' heads (no-drone baseline condition, 16 ft, 48 ft, and 82 ft). Drone flight height was measured relative to the roof surface.

4.3 Instruments

To simulate a realistic sloped-roof environment, a 6 ft × 6 ft wooden roof platform was constructed in the Integrated Construction Informatics Laboratory (ICIL) at West Virginia University (Figure 1). The platform was supported by adjustable wooden legs, allowing it to be set to three different roof pitches. Unity software was used to develop a virtual roofing worksite, with three distinct virtual roof scenes corresponding to each roof pitch condition. A virtual drone was also implemented within Unity and was modeled after the DJI Mavic 3 Pro, with corresponding real drone sound incorporated into the simulation. Figure 2 shows a sample virtual roof scene with the virtual drone developed in Unity.

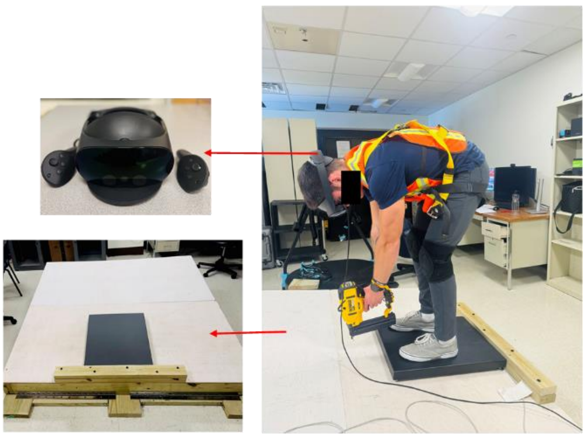

Figure 1. A participant performing a shingle installation task within a virtual roofing environment, using a VR headset while stooping on a force plate positioned on a wooden roof platform.

Figure 2. Sample virtual roofing site scene with a virtual drone

Prior to each trial, the virtual roof scene was aligned with the physical roof platform to ensure consistency in slope. As shown in Figure 1, participants were immersed in the virtual scene using a VR headset (Meta Quest Pro) and held a nail gun to simulate shingle installation tasks on a force plate (Bertec FP5060D-06-PT-2000) which was mounted on the wooden roof platform to record participants' COP data.

4.4 Procedure

At the start of the experiment, participants were provided with the IRB-approved informed consent form, which they were required to read and sign prior to participation. Participants then wore a high-visibility safety vest to simulate real roofing conditions and completed several practice trials to become familiar with the virtual environment. During the experiment, participants simulated a shingle installation task in a stooped posture by holding a nail gun while wearing a VR headset. Before each trial, the headset was calibrated to align the virtual environment with the participant's real-world position and orientation.

Each trial lasted 30 seconds and was performed on a force plate mounted on the wooden roof. The force plate was calibrated prior to each trial and recorded data at a sampling frequency of 100 Hz. The force plate was connected to a computer running Bertec Digital Acquire 4.3.1 software to enable continuous data acquisition throughout each trial. Participants were instructed to maintain their posture as steadily as possible but were allowed to move or respond naturally to any distractions caused by the drone.

The virtual drone followed a front-back and back-front flight path relative to the participant. Participants' front-back motion corresponded to the anterior-posterior (AP) direction, while side-to-side motion corresponded to the mediolateral (ML) direction. To enhance realism, the simulation presented drone sounds in a way that reflected their position and distance from the participant, allowing them to perceive the drone's flying noise spatially in stereo as it moved through the virtual environment. The experiment included three roof slope conditions and four drone flight conditions, resulting in a total of 12 experimental scenarios. Scenario order was randomized first by roof slope and then by drone condition to minimize order effects. Each participant completed all 12 scenarios.

4.5 Data Processing

The virtual drone was programmed to move in a front-back flight path between 8 and 26 seconds of each 30-second trial. Although force plate data were collected for the entire 30 seconds, the first 5 seconds and the final 2 seconds were excluded from analysis to minimize the influence of initial transients and anticipatory adjustments. This analysis window was selected to specifically capture participants' postural responses to the drone distraction.

To account for variability in participants' foot placement, COP trajectories were centered relative to their arithmetic mean, following standard procedures used in previous studies [22]. Force plate data were then used to evaluate sway in the ML and AP directions, denoted as COP_X and COP_Y, respectively. Postural stability was quantified using sway area, a widely used metric, representing the total area covered by COP movement during the balance task. Larger sway area values indicate greater postural instability [23].

4.6 Data Analysis

A repeated-measures linear mixed-effects model was employed to analyze the data. Participants were treated as a random effect to account for inter-individual variability. This approach controls for between-subject differences and reduces confounding due to subject-specific variability in estimating the effects of the experimental factors. Previous scene, scene, order, drone height, and roof slope were modeled as fixed effects.

Type III ANOVA was used to determine the statistical significance of each fixed effect, with significance set at $p < 0.05$. Post hoc pairwise comparisons were conducted to examine differences between specific conditions. All analyses were performed using the lme4 and lmerTest packages in R [24, 25].

5 Results

5.1 Statistical Effects of Drone Height, Slope and Their Interaction

Table 1 presents the results of the statistical models, with values indicating p-values for each effect. Drone height had a statistically significant impact on postural sway, whereas roof slope did not. Additionally, the interaction between drone height and roof slope was not statistically significant.

Table 1 Result of the mixed model

Independent Variable	Sway Area
Drone Height	< 0.001
Roof Slope	0.1065
Drone Height*Roof Slope	0.1401

5.2 Main effect of Drone Condition

Table 2 presents the results of pairwise comparisons between drone altitude conditions. A significant difference was observed between the no-drone condition and the 16 ft drone condition. Significant differences were also found between the no-drone condition and the 48 ft and 82 ft conditions, although these effects were generally less pronounced than at 16 ft. Specifically, the 48 ft condition showed moderate significance, whereas the 82 ft condition exhibited a stronger effect. Comparisons also indicated that the 16 ft versus 48 ft contrast also yielded a significant difference.

Table 2 Pairwise comparison between drone conditions

Drone Conditions	Sway Area
No drone – 16ft	<0.001 ***
No drone – 48ft	0.016*
No drone – 82ft	0.003**
16ft – 48ft	0.024*
16ft – 82ft	0.084
48ft – 82ft	0.592

*p < 0.05; **p < 0.01; ***p < 0.005.

5.3 Main Effect of Slope

No significant effect of slope was observed for sway area. The effect of slope was not as strong as expected, possibly due to the dominant influence of drone distraction.

5.4 Interaction Effect of Drone Height and slope

No significant interaction was found between drone height and roof slope. This indicates that the effect of drone height on roofers' balance is independent of roof slope, and vice versa. Each factor can therefore be interpreted separately, as the effect of one factor does not depend on the level of the other.

6 Discussion

This study developed a controlled, VR-based experimental protocol that integrated immersive visual and auditory drone cues with realistic roofing scenarios. The protocol was used to investigate how drone flight height affects the postural stability of roofers performing stooped tasks on sloped surfaces, with sway area as the measure of balance. The findings suggest that the presence of a drone affected participants' stability. Drone height consistently influenced sway area ($p < 0.005$), with the greatest instability observed at the lowest altitude (16 ft). These results suggest that drones operating in close proximity, due to stronger visual and auditory cues, may influence participants' balance, as postural adjustments increased when the drone was closer. Although attention was not directly measured, these postural changes indicate that participants were responding to the drone's visual and auditory signals, as reflected in changes in their stability on the roof.

Interestingly, the 82 ft condition also resulted in significant deviations from the no-drone baseline, although it did not differ significantly from the 16 ft condition. This effect may reflect participants responding to auditory cues without immediate visual confirmation of the drone, which led them to search for its location and make additional postural adjustments. Previous studies have shown a similar phenomenon, indicating that auditory input becomes especially important for maintaining stability when visual information is limited, highlighting the compensatory role of the sensory system in balance control [26]. In contrast, at 48 ft, the drone was visible but less proximate, allowing participants to better contextualize its location. While sway area remained elevated relative to the baseline, the effect was less pronounced than at 16 ft or 82 ft.

On the other hand, roof slope did not produce a statistically significant effect. It is possible that the strong influence of the drone presence overshadowed any slope-related changes. Contrary to previous studies suggesting that inclined surfaces impair postural stability [27], participants in this study showed slightly improved balance on steeper slopes. This may reflect adaptive behavioral strategies, as higher-threat conditions such as steeper surfaces likely increase attentional focus and induce postural stiffening, consistent with prior reports on balance under challenging conditions [28]. In this Study, novice individuals were chosen to examine initial balance responses to sloped surfaces with drone distractions without relying on experience-based strategies. Because novice workers are generally more injury-prone and benefit from hands-on training, this study offers an initial experimental framework to guide future training and safety guidelines for drone use around roofers.

By quantifying COP sway across different roof slopes and drone altitudes, this study provides a systematic assessment of the effects of drone presence on postural control. Despite these important contributions, this study has some limitations. First, postural stability was quantified exclusively using sway area derived from COP data and directional COP measures (AP and ML) were not examined. Future studies should incorporate additional balance metrics to achieve a more comprehensive characterization of postural control. Second, this study examined shingle installation task in roofing context; however, roofing work involves a wide range of tasks with varying physical demands, and drone-related distractions may affect balance differently across activities. Future studies should therefore consider other types of roofing tasks to better capture the broader impact of drone presence. Lastly, drones vary in characteristics such as speed, noise, and size, which may influence the level of distraction. Future studies should examine these factors to further clarify their individual and combined effects on roofer safety.

7 Conclusions

This study introduces a repeatable experimental protocol that combines immersive VR with realistic task simulation to evaluate the influence of drone use in roofing environments. The results show that drone presence affects roofers' postural stability during awkward working postures, such as stooping on sloped surfaces. Drones flying at closer distances produced greater distraction and increased the risk of balance loss, which is especially critical for roofers working at height.

The findings of this study emphasize the need for comprehensive safety protocols that address drone-induced distractions. Such measures may include limiting drone flights to designated altitudes to reduce visual and auditory interference for roofers, particularly during high-risk tasks on elevated and sloped surfaces. In addition, enhancing roofer training to better manage external distractions and incorporating their feedback into drone operation guidelines may further improve safety on roofing sites.

8 Acknowledgements

This study was supported by the National Institute for Occupational Safety and Health (NIOSH) under Project No.: 1R21OH012455-01A1. The authors also thank Dr. Steven Cain at West Virginia University for his assistance with the force plate used in this study, as well as the participants who voluntarily took part in the experiment. The findings and conclusions presented in this paper are those of the authors and do not necessarily represent the official position of NIOSH or the Centers for Disease Control and Prevention.

References

[1] J. R. Moore and J. P. Wagner, "Fatal events in residential roofing," *Safety science,* vol. 70, pp. 262-269, 2014.

[2] H. Hsiao and P. Simeonov, "Preventing falls from roofs: a critical review," *Ergonomics,* vol. 44, no. 5, pp. 537-561, 2001.

[3] D. Wang, F. Dai, X. Ning, R. G. Dong, and J. Z. Wu, "Assessing work-related risk factors on low back disorders among roofing workers," *Journal of construction engineering and management,* vol. 143, no. 7, p. 04017026, 2017.

[4] M. N. Glinka, T. B. Weaver, and A. C. Laing, "Age-related differences in movement strategies and postural control during stooping and crouching tasks," *Human Movement Science,* vol. 44, pp. 246-257, 2015.

[5] P. I. Simeonov, H. Hsiao, B. W. Dotson, and D. E. Ammons, "Control and perception of balance at elevated and sloped surfaces," *Human Factors,* vol. 45, no. 1, pp. 136-147, 2003.

[6] J. Irizarry, M. Gheisari, and B. N. Walker, "Usability assessment of drone technology as safety inspection tools," *Journal of Information Technology in Construction (ITcon),* vol. 17, no. 12, pp. 194-212, 2012.

[7] J. Howard, V. Murashov, and C. Branche, "Can Drones Make Construction Safer?," *Centers for Disease Control and Prevention,* 2017.

[8] I. Jeelani and M. Gheisari, "Safety challenges of UAV integration in the construction industry: Focusing on workers at height," *University of Florida,* 2022.

[9] N. Hishsan, A. Salleh, and N. Zin, "Application of unmanned aerial vehicle (UAV) for a safer roof inspection at high rise building," in *IOP Conference Series: Earth and Environmental Science*, 2024, vol. 1347, no. 1: IOP Publishing, p. 012023.

[10] S. Yildiz, S. Kivrak, and G. Arslan, "Using drone technologies for construction project management: A narrative review," *Journal of Construction Engineering, Management & Innovation (Online),* 2021.

[11] M. Hatoum and H. Nassereddine, "The use of Drones in the construction industry: Applications and implementation," in *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*, 2022, vol. 39: IAARC Publications, pp. 542-549.

[12] M. C. Tatum and J. Liu, "Unmanned aircraft system applications in construction," *Procedia Engineering,* vol. 196, pp. 167-175, 2017.

[13] R. L. Finn and D. Wright, "Unmanned aircraft systems: Surveillance, ethics and privacy in civil applications," *Computer Law & Security Review,* vol. 28, no. 2, pp. 184-194, 2012.

[14] H. I. Moud *et al.*, "Qualitative assessment of indirect risks associated with Unmanned Aerial Vehicle flights over construction job sites," in *ASCE International Conference on Computing in Civil Engineering 2019*, 2019: American Society of Civil Engineers Reston, VA, pp. 83-89.

[15] M. Namian, M. Khalid, G. Wang, and Y. Turkan, "Revealing safety risks of unmanned aerial vehicles in construction," *Transportation research record,* vol. 2675, no. 11, pp. 334-347, 2021.

[16] G. Albeaino, P. Brophy, I. Jeelani, M. Gheisari, and R. R. Issa, "Impact of drone presence on construction individuals working at heights," *Journal of Construction Engineering and Management,* vol. 149, no. 11, p. 04023119, 2023.

[17] H. Izadi Moud, I. Flood, X. Zhang, B. Abbasnejad, P. Rahgozar, and M. McIntyre, "Quantitative assessment of proximity risks associated with unmanned aerial vehicles in construction," *Journal of Management in Engineering,* vol. 37, no. 1, p. 04020095, 2021.

[18] A. Ryan, C. Fitzpatrick, E. Christofa, and M. Knodler Jr, "Driver performance due to small unmanned aerial system applications in the vicinity of roadways," *Transportation research part F: traffic psychology and behaviour,* vol. 68, pp. 118-131, 2020.

[19] I. Jeelani and M. Gheisari, "Safety challenges of UAV integration in construction: Conceptual analysis and future research roadmap," *Safety science,* vol. 144, p. 105473, 2021.

[20] G. Albeaino, I. Jeelani, M. Gheisari, and R. R. A. Issa, "Attentional Impact of Drones on Construction Sites," *Proceedings of 59th Annual Associated Schools,* vol. 4, pp. 121-129, 2023.

[21] D. Gouwanda, A. A. Gopalai, Z. Lim, and K. Lim, "Measuring human balance on an instrumented dynamic platform: a postural sway analysis," in *The 15th International Conference on Biomedical Engineering: ICBME 2013, 4th to 7th December 2013, Singapore*, 2014: Springer, pp. 496-499.

[22] H. Qiu and S. Xiong, "Center-of-pressure based postural sway measures: Reliability and ability to distinguish between age, fear of falling and fall history," *International Journal of Industrial Ergonomics,* vol. 47, pp. 37-44, 2015.

[23] A. Merlo *et al.*, "Postural stability and history of falls in cognitively able older adults: The

Canton Ticino study," *Gait & posture,* vol. 36, no. 4, pp. 662-666, 2012.

[24] D. Bates, M. Machler, B. Bolker, and S. Walker, "Fitting linear mixed-effects models using lme4," *Journal of statistical software,* vol. 67, pp. 1-48, 2015.

[25] A. Kuznetsova, P. B. Brockhoff, and R. H. Christensen, "lmerTest package: tests in linear mixed effects models," *Journal of statistical software,* vol. 82, pp. 1-26, 2017.

[26] M. Dozza, F. B. Horak, and L. Chiari, "Auditory biofeedback substitutes for loss of sensory information in maintaining stance," *Experimental brain research,* vol. 178, no. 1, pp. 37-48, 2007.

[27] C. Wade and J. Davis, "Postural sway following prolonged exposure to an inclined surface," *Safety science,* vol. 47, no. 5, pp. 652-658, 2009.

[28] M. G. Carpenter, J. S. Frank, C. P. Silcher, and G. W. Peysar, "The influence of postural threat on the control of upright stance," *Experimental brain research,* vol. 138, pp. 210-218, 2001.