# Effects of Context on Performance Times in Residential Roofing

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In residential constructions, falls are the most serious causes of all fatal injuries. The elevation of these falls are relatively lower in almost all cases. Although there are rules for the usage of proper fall arrest systems (FAS) during the construction works, these rules are not properly enforced in residential roofing. In this research by using two types of FASs across two scaled models, different performance times (don time, doff time, tar paper setting time and shingle setting time) were measured. Two scaled models were built in indoor and outdoor location to see whether change of context affects the performance times. Data were analyzed by using SAS 9.4™.

## INTRODUCTION

In the construction sector, falls are common causes of injuries and fatalities. Among the fatalities and injuries occurring on construction sites, many incidents and accidents were found on residential sites where fall heights are relatively low and personal protective equipment are not common. In 2013, a total of 699 people died due to falls, slips and trips. Falls to lower level accounted for 82% of those fatalities (BLS, 2013). A study by Huang and Hinze (2003) demonstrated that most fall accidents took place at elevations of less than 9.15m (30 ft) occurring primarily on new construction projects of commercial buildings and residential projects of relatively low construction cost.

Falls in the construction industry represent a major safety hazard that must be addressed. According to BLS data of 2012, about 12% of injuries occurred at the lower levels and 45% of the falls to a lower level involved falls of 20 feet or less. Although statistics have not been adequately established for falls in residential construction, the attributes of residential construction provide a relatively higher risk context compared to commercial construction. These attributes include the lower degree of regulation of residential construction, the likelihood of non-union companies with fewer opportunities for training, and the relatively rapid turn-around of a work project that allows little time for inspection or enforcement (Clark, 2008).

Smith-Jackson et al. (2011) explored the barriers for not using the fall arrest systems among residential and post frame workers. The factors that are significant to the roofers are low roof pitch, difficult to doff and don the harness, increment of fall hazards, difficulty in movement, discomfort after wearing the harnesses and rope entanglement with different parts of the body. When they use PPE, their original workflow slows down(Hung, Smith-Jackson, & Winchester, 2011).

In typical residential construction practices, workers do not use the appropriate anchorage point or typical equipment especially for a second story floor. For fall arrest systems (FAS), workers spend large amounts of time adjusting lanyards, which may decrease their productivity (Lederer, Choi, & Griinke, 2006). If the workers need to adjust the FAS all the time, their performance can be hindered and they can face unwanted injuries Hsiao, Friess, Bradtmiller, and Rohlf (2009). Performance degradation using the conventional FAS has been studied by Sa, Seo, and Choi (2009). This decreased performance can contribute to unwillingness to use PPE. All of these obstacles must be overcome to develop effective work systems to prevent falls and to increase user compliance.

Usability of fall arrest systems conducted on construction sites are problematic due to difficulties in measurement, interference of environmental variables, and bias of workers due to researcher presence. Weather condition such as heat, lighting, noise level, participant selection criteria, work procedure, physical setup and equipment used are some of the important features that should be considered when choosing the appropriate model for the research. Reduced direct solar gain, privacy, working in quiet indoor conditions, or noisier outdoor conditions could influence performance and attitude outcomes (Clements-Croome, 2006).

However, it is important to keep in mind that workers' decisions are not affected by a controlled environment. Tests in a protected environment with access to large, standardized testing apparatuses provide many advantages, however, have limited applicability to the real world of construction (Bernold & Lee, 2010). Scaled world models may provide means to test fall arrest system design and investigate usability issues, which may be not feasible in the field setting due to ethics and risk (Angles, Trochez, Nakata, Smith-Jackson, & Hindman, 2012).

## OBJECTIVE

The objective of this study is to compare the indoor and outdoor scaled models in terms of performance times. Performance times were measured by four tasks time— donning, doffing, tar paper installation and shingle installation. Two scaled models were built in two contexts to examine the effects of context on performance times.

## METHOD

### Research Design

Quantitative data was collected from two different sites where other constructs such as— scaled models, participants' selection criteria, work procedure, apparatus, remained same. These two groups were from North Carolina A&T State University (outdoor model) and Virginia Tech (indoor model). The outdoor scaled model was built using the replica of the indoor study at Virginia Tech. The hypotheses to

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be tested was no differences would be found between the indoor and outdoor models in terms of performance time.

Participants were studied against a specific context and harness type. The experimental design used a 2x2 between subjects design (Table 1).

Table 1

*Design of study*

| **Context** | **Harness Type** | |
|---|---|---|
| | **Low-grade** | **Mid-grade** |
| **Indoor** | 16 | 16 |
| **Outdoor** | 16 | 16 |

**Apparatus**

*Roof Structure*: The roofing apparatus was a 14 ft. X 10ft. X 8ft. wooden roof structure consisting of six trusses mounted on a cement foundation (Figure 1).

*Figure1: Indoor and outdoor scaled model.*

Trusses were spaced 2 feet on center .The platform was sloped in a similar way of actual residential roof where the pitch was 6:12.

*Fall Arrest System and Anchor:* In this study, two different types of harnesses were used- 1) low level harness with no padding and one size fits to all, 2) Mid- range harness where there is some pad over the shoulder area and some adjusting features. Participants were asked to wear one of the harnesses .The harnesses were tethered to a self-retracting lifeline which act as a seat belt to protect the worker to go beyond a minimal distance of 6 feet (1.8 m).

There were two anchorages to be tested: metal braced and tie-off. The anchorages were tied with the trusses of the roof .One part of the lifeline needs to attach to the anchorage while the lower end is attached to the back of the harness. The participants were asked to do the roofing task wearing the harness and tied to the anchorage by the lanyard.

**Dependent and Independent Variables**

Two independent variables— context and harness type and four dependent variables were considered for analysis. The dependent variables were don time (time to don the harness), doff time (time to doff the harness), tar time (time to install the tar paper wearing the harness) and shin time (time to set the shingles over tar paper wearing the harness).

**Participants**

Total sample size was sixty four (n=64). Among the participants two (2) were female and the rest were male. The following criteria were used for the selection of the participants: 1) participants had to be at least 18 years of age and weigh 310 lbs or less 2) no injury in the previous year 3) had at least one year of roofing experience and 4) had been employed with a construction company for at least one year at some point in time.

The mean age of the participants was 36.9 years (*SD*= 10.46), mean height was 70.34 in. (*SD* = 3.37) and mean weight 188.69 lbs. (*SD* = 35.09). These participants had a mean roofing experience of 10 years (*SD* = 9.7). Among these participants, 31% were African-American, 44% were European-American, 14% Hispanic, 3% Asian-American and 8% from other ethnic groups (Table 2).

Table 2

*Comparison of demographics for indoor and outdoor context*

| **Characteristics** | **Mean (SD) /Total (%)** | **Indoor (n=32)** | **Outdoor (n=32)** |
|---|---|---|---|
| **Age** | 36.9 (10.46) | 36.8 (10.7) | 37 (10.45) |
| **Weight lbs** | 188.69 (35.09) | 181.66 (27.89) | 195.06 (39.74) |
| **Height(inch)** | 70.34 (3.37) | 70.89 (3.80) | 69.83 (2.91) |
| **Roofing Experience** | 10.06 (9.7) | 12.30 (10.47) | 7.82 (8.14) |
| **Ethnicity** | | | |
| African American | 20 (31.25%) | 1 (3.1%) | 19 (59.4%) |
| Asian American | 2 (3.12%) | 1 (3.1%) | 1 (3.1%) |
| EA/Caucasian | 28 (43.75%) | 21 (65.63%) | 7 (21.9%) |
| Native American | - | - | - |
| Hispanic | 9 (14.06%) | 4 (12.5%) | 5 (15.63%) |
| Other | 5 (7.81%) | 5 (15.63%) | - |

**Procedure**

The participants signed the consent paper allowing the use of video recorders on the eve of the experiment. Participants' demographics were taken by using a Demographic questionnaire. Participants were asked to don one of the harnesses without any assistance from the investigators. Counterbalancing was used to determine the order of harness assignment. After donning task, the harnesses were adjusted to ensure they were wearing correctly. Participants were provided with a tool belt, hard hat, knee pads, gloves and goggles. Knee pads, goggles and gloves were optional. Participants were asked to complete two roofing tasks while wearing one of two fall arrest harnesses (low-cost version; medium-cost version). The two roofing tasks were to apply tar paper over the existing sheathing (oriented strand board/OSB) followed by laying two rows of shingles on the roof. Finally, participants were requested to take off the harnesses. The whole task was videotaped and time was measured by a stopwatch.

**Data Analysis**

Data was analyzed using SAS 9.4™. A Shapiro-Wilk test of normality was used to test the normality of the dependent variables. Distributions were non-normal, thus to explore associations, we used Spearman rho correlations. Repeated measure ANOVA was used to examine significant differences among dependent variables. A post-hoc test using contrast method examined the paired differences across all the variables. Significance level was set to be alpha, $\alpha= 0.05$.

## RESULTS

The descriptive statistics for this study are summarized in Table 3.The mean don time increased with a change of context from indoor to outdoor by 93%, while the time for tar paper installation increased by 47%. The increments of mean shin time and doff time were 30% and 57%, respectively, from indoor to outdoor context.

*Table 3*

*Mean (standard deviation) of the all response variables*

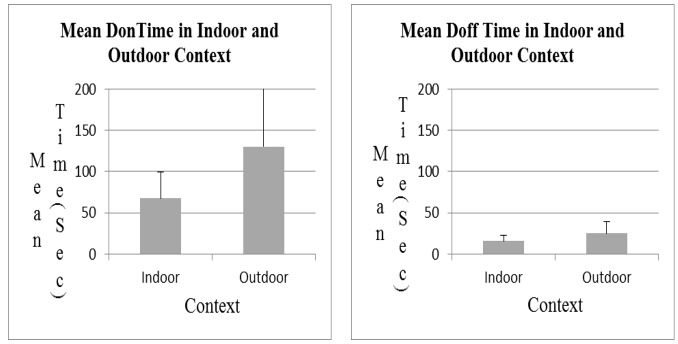
| Dependent Variables | Context | |
|---|---|---|
| | **Indoor (n=32)** | **Outdoor (n=32)** |
| **Don Time** | 67.55(32.08) | 130.36(75.98) |
| **Tar Time** | 238.53(101.55) | 351.1(516.18) |
| **Shin Time** | 356.63(149.94) | 462.19(292.63) |
| **Doff Time** | 16(6.98) | 25.15(14.51) |

Results from the repeated measure ANOVA established that the mean performance time changed across different level of times, Wilks' $\lambda= 0.18$, $F\ (3, 54) = 83.13$, $p < .0001$.It was also found that the change in mean performance time across four different levels were significantly influenced by the change of context, Wilks'$\lambda= 0.81$, $F\ (3, 54) = 4.15$, $p = .01$. Other effects were found insignificant.

A main effect for context was found. It was identified that indoor and outdoor context were significantly different for performance times, $F\ (1, 56) = 3.73$, $p=.05$.

Univariate results for the relationship indicated that the effect of context was significant for mean don time, $F\ (1, 56) =17.08$, $p=.0001$ and as well as mean doff time, $F\ (1, 56) = 10.71$, $p= .001$. Mean don time ($M$= 130.36, $SD$=75.9) at outdoor context is significantly higher than the mean don time at indoor context ($M$=67.55, $SD$=32.08). Also, mean doff time in the outdoor context ($M$= 25.15, $SD$=14.51) was significantly higher than mean doff time in the indoor context ($M$=16, $SD$= 6.98).

Figure 2 represents context effect over mean don time and doff time. In both cases high significant effects have been found for outdoor context. Error bars represent standard deviation over the mean values.




(a) (b)

*Figure 2: Comparison of (a) mean don time (b) mean doff time in indoor and outdoor context*

A post-hoc test using contrast method identified that mean don time ($M$= 98.96, $SD$=64.55) was significantly different from mean tar time ($M$=294.82, $SD$=361.86) (p<.0001), mean shin time ($M$=409.41, $SD$=233.82) (p=.001) and mean doff time ($M$=20.58, $SD$=12.17) (p<.0001). Mean tar time ($M$=294.82, $SD$=361.86) was found to be significantly different from mean shin time ($M$=409.41, $SD$=233.82) (p<.0001) and mean doff time ($M$=20.58, $SD$=12.17) (p<.0001). Mean shin time ($M$=409.41, $SD$=233.82) (p=.001) and mean doff time ($M$=20.58, $SD$=12.17) (p =.002) were also significantly different.

Spearman's rho was computed to assess the relationship between four performance times as these variables were found non-normal. Significant p-values are shown in Table 4.

*Table 4*

*Correlation Analysis for performance times*

| | **DonTime** | **TarTime** | **ShinTime** | **DoffTime** |
|---|---|---|---|---|
| **DonTime** | - | | | |
| **TarTime** | .41*** | - | | |
| **ShinTime** | .36*** | .59*** | - | |
| **DoffTime** | .41*** | .41*** | .45*** | - |

* p<.05.

** p<.01.

*** p<.00.

## DISCUSSION

The objective was to identify whether significant differences existed between indoor and outdoor scaled models when four of the performance times such as don time, doff time, tar time and shin time were considered. Significant positive correlations were found among these variables except between don time and tar time.

A significant time effect was found across four different performance times. All these tasks are different. The nature and level of complexity for each task demanded more or less time in each case. Also, individual work skill may have some influence on the task time.

Further analysis identified that the change of context also affects the performance times. As stated earlier, two scaled models were established in two places—one in a closed environment and another in an open environment. The environmental attributes may affect the four task times in this respect. A main effect for context identified that indoor and outdoor scaled models may differ.

However, no overall harness effect was found in the participants' performance time. It implied that no matter which harness was used, participants' performance would not significantly vary. In residential roofing, most of the small construction companies do not provide their roofers with harnesses. Thus, the participants may not be familiar with the use of harnesses and the complexity level may be similar for both of the tested harnesses.

Univariate results for the four times explored that mean don time and doff time in the outdoor context were significantly greater. Participants of the outdoor context took more time to don and doff their respective harnesses compared to the indoor participants. The donning and doffing time may be affected by the attributes of the environment. As the participants in the indoor scaled model donned and doffed the harnesses in a soothing environment with no sunlight or noise and fixed temperatures with low humidity, they may have taken less time in these tasks. However, participants' demographics were found to be not related to any of these performance times.

## CONCLUSIONS

Based on the result found in this study, it can be inferred that in terms of roofing tasks, the indoor scaled model is as valid as the outdoor scaled model. The study which involves continuous and monotonous, i.e., routinized work with less variation, the indoor scaled model may be more appropriate and cost effective. However, donning and doffing the harness employs more time in the outdoor context compared to the indoor context. The time for donning and doffing procedures are a crucial concern for the usability of FAS. Therefore, we should consider the outdoor environment to be more significant. In decision intensive study where time and accuracy both are crucial concerns for the complex decision making and multiple contextual factors (i.e., environmental) are known to influence the decision making, outdoor study can be recommended. Also, for future research, some more factors need to be considered such as, time exposure on the roof, participant's body dimension, roof pitch and the height of the scaled model.

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