



Portable ladder assessment tool development and validation – Quantifying best practices in the field

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ABSTRACT

Many causes for falls from ladders in construction are related to the user's activities; however, the extent to which users comply with ladder use best practices is unknown and has not been well quantified before. We developed and tested an audit tool that assesses compliance with best practices guidelines for portable-ladder-use designed for applications in the construction industry. Implemented on a hand-held computer, the assessment tool consisted of a series of check-lists categorized in four groups; ladder condition, setup, moving on a ladder, and completing tasks from a ladder. For these four observational categories, the resulting tool contained 31 and 33 questions for step and extension ladders, respectively. Three individuals trained to use the tool scored a set of photographs and videos depicting 25 ladder conditions, 20 ladder setups, 10 users moving on ladders, and 13 users completing tasks from a ladder for a total of 78 observations. The assessment tool had good agreement across and within raters. For the three raters, agreement ranged from 79% to 97% across the questions. Within one subject, kappa coefficients for the intra-rater reliability ranged from 0.67 to 0.91. The tool offers a practical method to quantify best practices associated with ladder use that can ultimately inform targeted intervention efforts.

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1. Introduction

Falls from ladders are a serious and often overlooked cause of falls. In the United States construction industry, falls from ladders are responsible for 16% of all fatal injuries and 24% of non-fatal injuries that involved days away from work (CPWR, 2008). These falls can often disable workers (Smith et al., 2006). Nearly 40% of workers with ladder-related injuries were absent from work for more than a month (Axelsson and Carter, 1995) and half of those injured “experienced continuing, possibly permanent disability”. A majority of these ladder injuries involve portable ladders.

While many efforts have developed specific design standards (e.g. ANSI A14, ANSI 2000) for ladder safety, many of the causes for falls are related to their use (Cohen and Lin, 1991). Cohen and Lin (1991) reported the leading activities involved in falls from ladders included overreaching (19%), slipping on rungs (14%), and miss-stepping on rungs (10%). Other causes reported were failing ladder structure (9%), being struck by or attempting to catch/avoid falling objects (8%), applying excessive force (7%), leaning ladder against structure (7%), transitioning onto or from ladders (6%), standing on top rung (6%), unevenness or slipperiness of surface (5%), and other miscellaneous fall accidents (9%).

Workplace audits that measure the presence of fall hazards provide a comprehensive evaluation tool to assess fall hazards within a worksite (e.g. Becker et al., 2001). These tools allow for researchers and practitioners to quantify compliance with fall protection best practices. Implemented on a hand-held computer, their tool allows for easy use, portability, and instant feedback to the user on the performance of a worksite. Quantifying compliance with best practices can be used as feedback to measure the effectiveness of an implemented intervention. This previously developed audit tool, however, devote relatively limited attention to ladder-specific issues.

Therefore, we aimed to develop a best practice portable-ladder-use assessment tool implemented on a hand-held computer in order to optimize portability and report generation to assist researchers and practitioners in identifying specific intervention targets to ultimately reduce falls from ladders. After initial pilot testing and refinement we set out to test the inter-rater and intra-rater reliability of the tool through having trained raters score a set of photographs and videos depicting portable-ladder-use.

2. Methods and materials

The goal for the ladder use tool was to be able to quantify compliance to ladder use best practices at a construction work site for both managers and researchers to target specific interventions and

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to provide feedback on a site's performance. The tool should be portable and electronic providing easy data collection via a simple construction site walk-through. The inspiration of the tool comes from the West Virginia's Fall Safe tool, which evaluates all fall protection systems at the site using custom-designed software implemented on a hand-held computer (Becker et al., 2001). The goal here was limited to portable ladders; however, the tool can provide an inventory of alternative mobile elevated work platform tools at a site, such as aerial buckets, scissor lifts, and mobile scaffolding.

A hand-held computer (HP IPAQ) running Microsoft Mobile Windows provided the platform for the tool allowing for interface design as well as automatic storage and data organization. The check-list was programmed in LabView (National Instruments, Austin, Texas) and data were saved to a tab-delimited text file.

The first definition for the unit of analysis was a ladder with a single observation made up of all four categories for a single ladder. Those four categories were condition, setup, moving on a ladder, and working on a ladder. However, upon trial field use observing a single ladder often resulted in multiple observations of a single category and none in another category for a given ladder. For example, multiple people moving on an extension ladder setup to access a different level were observed; however, there were no observations of working on the ladder. Therefore, the definition for the unit of analysis was modified to be an observation of any of the four categories. A ladder therefore could have from 1 to 4 categorical observations and multiple observations within three of the four categories, depending on the timing of the observation and the situation of the ladder and its use.

For each of the four categorical observations, a single page contained all the yes/no check-list type of questions for the page, less than 8. For each question, a drop down menu was provided with four options, "Select One" – the default display that was associated with a passive not answered response, "Unknown", "Yes", or "No". All questions were setup for affirmation of compliance with best practice. Some questions do not apply to all situations, such as, "is the worker tied off", which applies for working at levels where a fall of greater than 6 feet could occur. In these instances, raters were instructed to leave a question unanswered. Each page also had a comment box to add any text to the observation record.

The questions were compiled from existing best practice guidelines and regulatory standards. For the extension ladder McCann (2005) provides a comprehensive list of best practices that include standards. For the step ladder a similar comprehensive list of best practices was compiled, using a similar format and structure as McCann.¹ In order to fit on the display, all questions were simplified to a few key words.

Raters were trained through an interactive training session and provided with a users' manual. The user's manual described the questions in detail, providing explanation of the shorten questions.² The interactive training program consisted of a discussion based class that included group exercises for the attendees to practice applying the tool.

Testing of the tool consisted of content validity by several experts, on-site usability, and inter- and intra-rater reliability. The specific questions were vetted among several experts at various meetings in the Boston area. The experts were members of the American Ladder Institute, the Association of General Contractors of Massachusetts, The Construction Institute (TCI) in Boston, Liberty Mutual Research Institute, The Center for Construction Research and Training, Area 1 Occupational Safety and Health Administration office, and the Department of Public Health in the

Commonwealth of Massachusetts. Modifications that resulted from feedback included simple changes in wording and the addition of job-made ladders.

Once implemented on a hand-held computer, the tool was taken to a field site for pilot testing. Here, the overall usability was tested by two raters. In addition to the already mentioned change in the unit of analysis, the ordering of questions was changed to facilitate the flow of responding to the questions.

To test the inter- and intra-rater reliability, three trained individuals scored 78 ladder observations (25 inspections, 20 setups, 10 moves, 13 working) presented via 22 photographs and 8 videos clips at a computer workstation. One rater scored the photographs and videos a second time six weeks later. Each rater completed the training program, participated in site visits and test, and used the tool at two construction sites. For each category we compared the agreement between the three raters using overall percent agreement. In addition we calculated Kappa Coefficients between the three raters (three comparisons) for the yes/no responses for each of the four categories (Rosner, 1995). We repeated these calculations for the two scores separated by six weeks for the one rater.

3. Results

The best practices assessment tool resulted in a total of 31 and 33 questions for all four observational classes for the step and extension ladders, respectively (Tables 1–3). Depending on the timing of observing a person work and move on the ladder it takes about 2–3 min to complete.

The practice assessment tool had good agreement across and within raters (Table 4). For the yes/no responses to the 78 ladder observations displayed in photos and videos, the inter-rater agreement ranged from 79% to 97% across the four observation classes and the three raters. The corresponding Kappa Coefficients ranged from 0.41 to 0.83 with half greater than 0.74 indicating good to excellent agreement across the raters (Rosner, 1995). For the one rater who evaluated the photos and videos twice with six weeks between evaluations, the reproducibility of scores were excellent with percentage of yes/no responses in agreement greater than 89% and Kappa coefficients greater than 0.67.

4. Discussion

The goal was to develop an assessment tool that quantified compliance with best practices for ladder use at a construction site. Through an iterative process involving the consultation of occupational health literature, researchers, professionals, and practitioners as well as pilot testing, a check-list based tool programmed on a hand-held computer was implemented and tested. The tool quantifies observations for ladder use as part of a safety walk-through at a construction site. Field testing supported its feasibility and the observational tests proved it was reliable in quantifying on-site ladder use practices.

The tool has many applications for both the practitioner and researcher. A construction manager can use the tool to complete daily walk-through and score their work site. Using the score they can identify areas for immediate attention and also see how the score changes on a day to day basis. For the researcher, the tool can be used similarly to mark areas for specific intervention studies as well as a marker for pre and post intervention measurements.

The tool was designed to measure compliance with best practices and as a result implicitly provides an inverse measure for risk for falls from ladders. Many safety programs rely on injury data for safety performance; however, based on the Heinrich pyramid (Heinrich et al., 1980), there are many more minor areas that can

¹ The step ladder guidelines have been submitted as supplemental material that will be available through the journal's web site.

² The manual has been submitted as supplemental material that will be available through the journal's web site.

Table 1
Product condition questions

| Display | Detailed question ^a |
|-----------------|--|
| Length | Categorical |
| Free of defects | Is the ladder free of major defects and does the ladder have all of its parts. |
| Is Type I | Is the ladder rated for 250 lbs or more |
| Has labels | Does the ladder have its labels and are they readable |
| Is setup | Is the ladder setup for use? |

^a Responses are unknown, yes, and no.

Table 2
Setup questions

| Display | Ladder | Detailed question ^a |
|---------------------|-----------|--|
| Flat/stable surface | Step | Is the step ladder on a flat and stable and hard surface? |
| Spreaders locked | Step | Are both spreaders that create the A-frame of the ladder fully engaged and locked? |
| Bottom secured | Extension | Is the bottom secured? |
| Proper angle 41 | Extension | By simple visual inspection is the ladder setup at a proper angle? |
| Top secure | Extension | Is the top secured? Is it tied off near the top to the structure it is touching? Are both rails supported? |
| Top > 3 feet | Extension | Does the top of the ladder extend above the top surface more than three feet (~3 rungs)? |
| Bottom clear | Both | Is the bottom of the ladder clear of loose materials that would provide a trip or slip hazard when stepping on/off the ladder. |
| Clear of electrical | Both | Is the setup clear of any electrical hazards? |
| Clean and dry | Both | Is the ladder clean of loose debris and dry? |
| In use | Both | Is the ladder in use? |
| Area marked off | Both | If the ladder is being used in a public area (non-construction personnel can access the area) is the work area marked off to warn passing individuals. |

^a Responses are unknown, yes, and no.

Table 3
Moving or completing tasks while on a ladder

| Category | Display | Detailed question ^a |
|----------|------------------|--|
| Both | Ladder type | Response is step, extension, or job |
| Both | Face ladder | Does the individual face the ladder when moving or working on the ladder? |
| Both | Off top steps | Does the individual not step on the top steps of the ladder? |
| Both | One person | Is there only one person on the ladder at a time? |
| Both | Belt buckle | does the person not over reach such that their "belt buckle" would go outside the two rails? |
| Both | 3 pt contact | Does the person have either two feet and one hand or two hands and one foot on the ladder touching the ladder when moving or do they not over reach keeping their center of gravity within the base of support while completing tasks on a ladder? |
| Move | Moves slowly | Do they move slowly and deliberately rather than rush up and down the ladder? |
| Move | Hand free | Are the users hands free of any tools or materials. |
| Move | On/off bot/top | Are the users getting on and off the ladder at the bottom or top (extension ladder) only? |
| Move | Checks stability | Before climbing do the users check stability of the ladder? |
| Work | Proper length | Is the length and location of the ladder such that the person does not have to complete the task with an extended reach over their head? |
| Work | One tool | Does the worker store unused tools in a tool belt or on a shelf on the ladder instead of holding multiple tools? |
| Work | Min forces | Does the worker minimize forces to complete the task? |
| Work | Worker tied off | If a fall from a ladder would be greater than 6 feet, is the worker tied off? |

^a Responses are unknown, yes, and no.

Table 4
Inter- and intra-rater reliability

| Interrater comparison | Inspect | Setup | Move | Work |
|--|---------|-------|------|------|
| <i>Percentage of yes/no responses in agreement</i> | | | | |
| A–B | 96% | 94% | 85% | 80% |
| A–C | 97% | 90% | 93% | 85% |
| B–C | 94% | 90% | 83% | 79% |
| <i>Intra-rater Comparison</i> | | | | |
| A1–A2 ^a | 99% | 97% | 89% | 93% |
| <i>Kappa Coefficients for yes/no responses</i> | | | | |
| A–B | 0.75 | 0.83 | 0.51 | 0.47 |
| A–C | 0.75 | 0.76 | 0.80 | 0.57 |
| B–C | 0.68 | 0.75 | 0.45 | 0.41 |
| <i>Intra-rater comparison</i> | | | | |
| A1–A2 | 0.90 | 0.91 | 0.67 | 0.78 |

^a Rater A completed the validation twice separated by six weeks.

be a better measure for safety performance. While not specifically measuring near-miss incidents, the tool measures potential for risk for incidents and therefore may provide a more sensitive measure

of changes at a work site that result from many factors including targeted interventions.

The observational tool behaved well for inter- and intra-rater reliability and reproducibility and when disagreements occurred, they were associated with questions that were less quantifiable from the figures. For example a question that was difficult from just the photos was whether a ladder was Type I. In a real work situation the ladder type is readily available if the ladder has labels. The purpose of using photographs and videos was to ensure each rater observed the same activities and, hence, controlled variability in the observed scenarios. Nonetheless, all the Kappa Coefficients were all in the "good to excellent" reproducibility ranges (Rosner, 1995).

The tool was designed strictly for portable-ladder-use – other quantification tools, some commercially available, exist for overall fall protection (e.g. Becker et al., 2001) and general safety for a construction site. The tool developed by Becker et al. (2001) includes measures of safety culture through interviewing construction supervisors and managers. The tool presented here does not

measure the policy and attitudes towards safety on a work site; however, the goal was that the compliance to best practices observed via the tool is associated with these attitudes and policies. Such associations, however, need to be examined in detail.

The design of the selected questions was to include affirmation of best practices and therefore, it was not possible to include all questions covering all possible non-compliance scenarios. An example of such a scenario is when the step ladder is setup like a straight ladder leaning on the wall. In this condition, the ladder would fail two basic setup questions: is the ladder on a flat stable surface and are the spreaders locked? Hence, such scenarios are incorporated into other questions, which decreases the overall score for that observed scenario. If an unanticipated scenario is observed, there is an opportunity to comment on these using the free-text comment for each observation class.

The other issue with any construction site safety assessment tool is determining an appropriate sampling strategy. Ladders come and go on a worksite according to both on-site trades and their corresponding work tasks. A walk-through only provides the observer with a single time to observe safety practices on site. For example, no extension ladders were observed at a recently visited work site. This may be due to the type of job or stage of construction. This circumstance was evident when we were collecting photographs and video of extension ladders. We had to coordinate with a few work site managers in order to time our visit to capture extension ladder use. Therefore, a representative sample will depend upon the specific goal of using the tool. If an evaluation of a construction project throughout the various stages of construction is desired, then multiple samples during the progress of a construction project would be necessary.

The tool measures compliance to best practices around ladder use; however, most prevention approaches target removing the falling hazard altogether, that is avoiding use of ladders. Many guidelines suggest that when planning a job supervisors, managers and workers should attempt to identify an alternative means of working at height including mobile scaffolds, scissors lifts, or even library ladders to complete the task, especially where repeat work is common such as electrical, HVAC, and plumbing installations. These devices, however, introduce their own dangers that need special consideration.

While the tool here focuses on portable-ladder-use and their associated best practices, it also measures the use of these alternative devices through a simple inventory system. Hence, simply through the inventory report, one can see how a site is reducing a specific fall hazard through these alternative devices.

The rater reliability tests reported here are a small set of tests that can evaluate the tool's performance. Other tests include sensitivity analysis to changes over time and construct validity (that is how well do these measures relate to falls?). These questions are important for any evaluation score; however, require extensive protocols and resources to answer. Reliability tests are often the first steps in tool development and these data suggest the portable ladder tool is robust to move onto these next levels of testing and performance measures.

In conclusion, the portable ladder best practices assessment tool proved to be a reliable measure for a cross-sectional view of a work site. It has many potential uses for both the researcher and safety practitioner.

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References

- American National Standards Institute (ANSI), 2000. 9: Selection, Care, and Use. In: A14.5 – 2000 American National Standard for Ladders – Portable Reinforced Plastic – Safety Requirements. Chicago, IL, American Ladder Institute.
- Axelsson, P.O., Carter, N., 1995. Measures to prevent portable ladder accidents in the construction industry. *Ergonomics* 38 (2), 250–259.
- Becker, P., Fullen, M., Akladios, M., Hobbs, G., 2001. Prevention of construction falls by organizational intervention. *Injury Prevention* 7 (Suppl. 1), 64–67.
- Cohen, H.H., Lin, L.J., 1991. A retrospective case-control study of ladder fall accidents. *Journal of Safety Research* 22, 21–30.
- Heinrich, H.W., Peterson, D., Roos, N., 1980. *Industrial Accident Prevention: A Safety Management Approach*. McGraw-Hill, New York, NY.
- McCann, M., 2005. Ladders. *Elevated Work Platforms and Scaffolding*. In: Manual, M., Burkart, J., McCann, M., Paine, D.M., Lapping, J., Joye, J. (Eds.), *Job Site Safety*. McGraw Hill, New York, pp. 313–350.
- Rosner, B., 1995. *Fundamentals of Biostatistics*, fourth ed. Duxbury Press, Pacific Grove, CA.
- Smith, G.S., Timmons, R.A., Lombardi, D.A., Mamidi, D.K., Matz, S., Courtney, T.K., Perry, M.J., 2006. Work-related ladder fall fractures: identification and diagnosis validation using narrative text. *Accident Analysis and Prevention* 38, 973–980.
- The Center for Construction Research and Training (CPWR), 2008. *The Construction Chart Book*. Silver Springs, Maryland.