ON IMPROVING SET-UP ANGLE ACCURACY FOR EXTENSION LADDERS

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The set-up angle for a straight extension ladder can influence the likelihood that the ladder will either slip out from the base or tip over at the top. The present study examined different methods of determining the set-up angle for ladders. Sixty-eight lay persons set up an extension ladder at three different heights (3.0, 4.3, and 5.2 meters), each using one of six methods—Basic, Stand-Reach, "L" Sticker, 75.5 degrees, 4-to-1, or a Bubble level. Results demonstrated that the Basic method (where participants were given no specific instructions) produced significantly more shallow set-up angles than any of the other five methods. The Bubble condition (where a bubble-level was provided on the side rail of the ladder) produced performance that was closest to the criterion of 75.5 degrees. All of the other methods produced intermediate set-up angles that were between the Basic and the Bubble conditions. These results indicate that assistive devices can be useful in promoting less-shallow ladder set-up angles.

INTRODUCTION

It has been estimated that ladders are associated with around 1-2% of all occupational injuries in industrialized countries (see Axelsson & Carter, 1995; Häkkinen, Pesonen & Rajamäki, 1988). One relatively common accident scenario concerns the issue of slip-out while using straight ladders. Slip-out occurs when the base of the ladder slips away from the vertical surface causing the user to fall with the ladder. Slip-out has been estimated to be associated with between 40% to 50% of straight ladder accidents (Björnstig & Johnson, 1988—reported in Axelsson & Carter, 1995; Häkkinen et al., 1988; Tyrens, 1980).

Slip-out occurs because of a loss of friction between the ladder footing and the surface on which it is placed. One issue that affects the propensity for slip-out is the set-up angle of the ladder. A steep set-up angle ensures that more of the force at the base of the ladder is vertical and not horizontal, reducing the likelihood of a slip-out. However, very steep angles decrease the stability of the user toward the top of the ladder and increase the possibility of ladder tip-over. Thus, there is a trade-off between the utility of different set-up angles and the propensity for slip-out or tip-over.

The optimum set-up angle that maximally reduces the chance of both a slip-out and a tip-over is not precisely known. However, there are recommended set-up angles that presumably account for these two competing concerns. For example, ANSI (1990) suggests that the proper set-up angle for a straight ladder is 75.5 degrees between the ladder and the ground.

Previous research on set up angles has generally demonstrated that, left to their own methods, people will generally set up a ladder at an angle that is more shallow than 75.5 degree. Häkkinen et al (1988) videotaped 21 power plant workers setting up and climbing a straight ladder and found that the mean set-up angle was 66.3 degrees (with a range of 57 to 76 degrees). Irvine and Vejvoda (1977) demonstrated that 97% of lay-people and carpenters set up straight ladders at angles between 68 and 71 degrees.

Bloswick and Crookston (1992) were able to improve set-up performance by providing participants with specific instructions about setting up the ladder and also by providing aids. These aids included a backward "L" sticker or a plumb-bob on the side rail. The present study sought to extend these previous findings by examining the effect of set-up instructions and aids on set-up angles for a straight extension ladder.

METHOD

Participants

Sixty-eight people participated in the present study—41 females and 26 males.[1] These participants, from the Eastern Massachusetts area, had a mean age of 37.0 years. Thirty-six of the participants owned a ladder. Overall, these participants used a ladder 2.1 times per year. Excluding those participants who did not use ladders at all during the previous year (n = 28), this mean-use figure rises to 3.8 per year. On a 1 ("Not at all familiar") to 10 ("Extremely familiar") scale, participants in this study reported a mean familiarity rating of 3.4. Only five participants reported ever having been injured while using a ladder, but 34 participants reported knowing someone who had been injured. In general, these participants could be considered relatively unfamiliar or inexperienced with ladders. Participants were recruited by newspaper advertisement and were paid for their participation.

1. One participant declined to provide demographic data.

Instructions

Participants were given one of six sets of instructions for setting up the ladder:

Basic: Participants were not given any specific criteria to meet (i.e., a target set-up angle) or method to use. Participants were instructed to set up the ladder the way they would if they were going to climb to the top.

Stand-Reach: Participants were told to set up the ladder such that they would be able to stand in front of it, place the tips of their toes against the feet of the ladder and rest their palms on the rung in front of them without having to bend their back or lean toward the ladder.

"L" Sticker: A backwards "L" sticker was placed on the side of the ladder. The ladder is set at the proper angle when the vertical part of the "L" is parallel with the wall and the bottom part of the "L" is parallel with the floor.

75.5 degrees: Participants were asked to set up the ladder at an angle of exactly 75.5 degrees. To assist participants in this task, they were shown the position of the ladder at 0 (lying on the floor) and 90 degrees (flat against the wall).

4-to-1: Otherwise known as the 25% rule, participants were asked to estimate the length of the ladder and then place the base of the ladder one-quarter of that length away from the wall. Thus, if the ladder was 4.0 meters tall, participants were to place the base of the ladder 1.0 meters away from the wall.

Bubble: A bubble level was attached to the side rail (much like the "L" sticker). Participants were asked to place the ladder such that the bubble in the level was perfectly centered within the two marks on the tube.

Materials

A 20-foot aluminum Type III extension ladder was used in the present study. This ladder allowed three separate heights to be evaluated: 3.0, 4.3, and 5.2 meters from the ladder's feet to its top. All original labels and markings were removed from the ladder.

Procedure

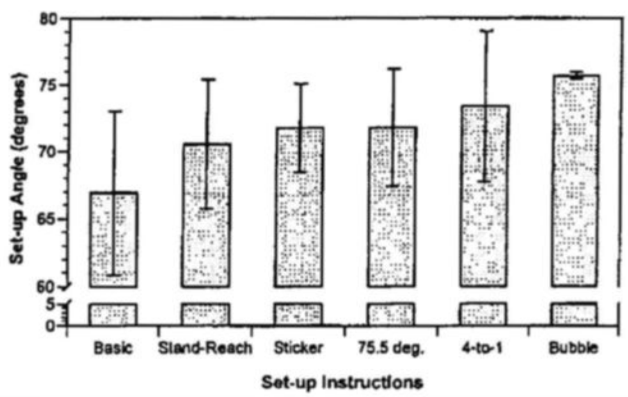
Participants performed the task of setting up the ladder one-at-a-time in a large, indoor laboratory with a 22-foot ceiling. Upon arriving at the Research Center, participants were instructed about the task and were asked to provide consent to participate. Participants were randomly assigned to one of the six set-up instruction conditions. Participants were instructed that they would be setting up the ladder three separate times—once at each of three different ladder heights. The height of the ladder for each of the three trials was randomized between participants.

The ladder was initially placed at an "unreasonable" angle (randomized as either unreasonably shallow or steep) so that participants would be required to adjust the position of the ladder. Once participants set up the ladder at the first height, they were asked to estimate the angle of the ladder. To assist them in this task, participants were provided shown (on paper) the position of the ladder at 0 and 90 degrees. Participants were then asked to estimate the height of the ladder (from its feet to its top). After providing this information, the ladder height was changed to one of the other two ladder heights (according to the experimenter's sheet) and the ladder was re-positioned to an "unreasonable" angle. After providing an estimate of the set-up angle and ladder height for this second trial, the ladder height was adjusted to the third height and the final trial was conducted. After completing all three trials, participants were asked some demographic questions and two measurements of body dimensions were taken—their standing height (from the floor to their shoulder) and their standing reach length (from their shoulder to the palm of their hand).

RESULTS AND DISCUSSION

A two-way mixed-model analysis-of-variance (ANOVA) was performed with set-up instructions as a between-subjects variable and ladder height as a within-subjects variable. The analysis showed a significant effect of set-up instructions, $F(5, 62) = 10.1, p < .001$. There was no significant effect for ladder height, nor was there any interaction between the two variables ($p > .05$). The means and standard deviations for the main effect of set-up instructions can be seen in Figure 1. Each set-up method will be discussed individually.

Figure 1: Mean set-up angle (with standard deviation bars) for each set-up condition



Basic Condition

According to a Fisher's Protected LSD post-hoc test, the Basic condition, in which no set-up methods were specified nor aids given, produced a significantly more shallow set-up angle (m = 66.9 degrees, SD = 6.1) than any of the other five conditions, $ps < .05$. This finding is consistent with previous research showing a marked tendency for people to set up a ladder at a relatively shallow angle when given no guidance to do otherwise (see Häkkinen et al., 1988).

Participants were asked to estimate the angle of the ladder after they had set it up. Interestingly, the mean estimated angle across ladder heights was 61.0 degrees. If participants had estimated that the set-up angle was steeper (i.e., ~75 degrees), then we might have concluded that people were simply underestimating the set-up angle. However, these results suggest that, without instruction, people generally *prefer* a more shallow set-up angle.

Stand-Reach

The stand-and-reach method produced the second-most shallow angle (m = 70.55, SD = 4.85). Statistically, this condition produced a steeper angle than the Basic condition, but a significantly more shallow angle compared to the 4-to-1 and Bubble conditions ($ps < .05$).

This method has been recommended in the past because it presumably results in less error than having people estimate distances or angles. However, there are some problems with this method that warrant mention here. First, palm placement on the rung of an extension ladder will change depending on the height of the ladder. An extension ladder is composed of two, equal-length segments. At the lowest ladder height, both segments will be fully lowered. Thus, an individual will have two rungs at the same level immediately in front of them. All of the participants using the Stand-Reach method with the 3.0- and 4.3-meter ladder lengths placed their palms on the ladder segment closest to them, which was several inches closer than the rung at the same height on the other (rear) ladder segment. With the ladder extended (i.e., at the 5.2-meter height), the front segment is elevated above the palm-reach of the participant and only the back rung (the one not previously used) is now the most accessible. Results from this study show that participants set up the ladder at a steeper angle with the 5.2-meter length (m = 72.7 degrees) than with the 3.0- (m = 70 degrees) or 4.3-meter (m = 68.2 degrees) lengths.

Second, this method is not realistically capable of producing angles very near 75.5 degrees. Irvine and Vejvoda (1977), using published anthopometric data, reported that 95% of males would be expected to set up a ladder between 70.7 and 71.7 degrees. The anthopometric data collected in this study suggest the same result. Using the two measures collected of all participants in this study (floor to shoulder height and shoulder to palm length), the overall predicted angle for this method would be 67.6 degrees. Looking at only the participants who were in the Stand-Reach condition, the predicted angle was 67.5 degrees and the actual angle (across all three ladder heights) was 70.6 degrees. Even with deviation in the way in which the method was apparently used, the resulting angles are significantly lower than the recommended 75.5 degrees.

The "L" Sticker

Participants who used the "L" sticker had a mean set-up angle of 71.8 degrees (SD = 3.31). This method produced significantly steeper set-up angles compared to the Basic condition and significantly more shallow angles than the Bubble condition ($ps < .05$).

75.5 Degrees

Surprisingly, this condition (m = 71.8 degrees, SD = 4.38) produced set-up angles that were statistically comparable to the "L" sticker and 4-to-1 conditions. Unlike the "L" sticker condition, the 75.5 degree procedure required users to make a perceptual judgment—a rather fine-tuned judgment. It was thought, beforehand, that this condition would produce quite variable performance. However, participants were able to set up the ladder at an angle that was fairly close to the recommended 75.5 degrees.

One note about this condition is warranted—participants were provided with information about the range of set-up angles for the ladder. Specifically, participants were told that if the ladder were set completely against the wall, it would have a set-up angle of 90 degrees. They were then told that if the ladder were laid on the floor, it would have a set-up angle of 0 degrees. Thus, participants did have some benchmark by which to judge the 75.5 degree angle. The *a priori* notion that this condition would prove difficult to participants was based on an understanding that people, in general, do not possess great knowledge about angles and would therefore have difficult in determining what 75.5 degrees would look like. A specific description of the boundaries of 0 and 90 degrees might be necessary for people to effectively use the 75.5 degree procedure.

4-to-1

The 4-to-1 condition produced set-up angles (m = 73.4 degrees, SD = 5.67) that were statistically similar to the Bubble condition. This finding was somewhat surprising, in that participants had to make a judgment about the length of the ladder and then transpose a fraction of that length onto a horizontal surface. The perceptual and mental tasks associated with this procedure was considered to be potentially difficult to participants.

It is possible to check participant's performance to determine the extent to which they actually made these judgments. For each of the three trials, participants were asked to estimate the height of the ladder (from its feet to its top). It is possible to generate an expected set-up angle based on this length estimate and compare the predicted angle with the participant's actual set-up angle. The estimated angle was generated by dividing the actual length of the ladder with a value that was equal to one-quarter of their estimate of the ladder's length and then taking the inverse cosine of this value. One of the participants had to be excluded from this analysis because of an estimate of ladder length that was out of bounds (60 feet). The results (presented in Table 1) show that the actual and estimated angles are quite similar. These angles are also very close to the angle that would theoretically be produced if this procedure were done with absolute accuracy (75.52 degrees). This finding suggests that participants did, indeed, perform some type of calculation as instructed.

Table 1: Actual and predicted angles for participants using the 4-to-1 set-up method

	Ladder Length (meters)		
	3.0	4.3	5.2
Actual Angle	74.1	74.9	72.9
Predicted Angle	74.9	75.8	74.5

Bubble Level

The Bubble level produced the most accurate and least variable performance of all the methods. The Bubble level (m = 75.66 degrees, SD = 0.26) produced significantly steeper set-up angles than all but the 4-to-1 condition (m = 73.37 degrees, SD = 5.67). Anecdotally, participants found this method to be very easy to use. Like the plumb-bob method evaluated by Bloswick and Crookston (1992), such precision devices allow users to set up a ladder with extreme accuracy. However, with both such devices, there are concerns about their practical use in real-world conditions. Such devices could be damaged or their accuracy reduced by the types of harsh treatment that ladders often receive during their life-cycle. The use of a Bubble level in this study was not based on whether it is a practical device that could or should be used on ladders, but rather it was used to determine if there were ways to overcome people's natural bias towards setting up ladders with a relatively shallow angle.

Preference for Shallow Angles

In all but the Basic condition, participants were asked to set up the ladder according to specific instructions. It was entirely possible that, upon setting up the ladder according to the particular instructions, participants might not prefer the resulting angle. Thus, after each trial, participants were asked "If you were going to climb the ladder right now, would you climb it as it is or would you move the base either closer or farther from the wall?" If they indicated that they would move the ladder, participants were asked to move the base to the position they would feel most comfortable climbing the ladder. The original angle was subtracted from the revised angle and a two-way mixed-model ANOVA was conducted with set-up instructions (minus the Basic condition) as the between-subject variable and ladder height as the within-subjects variable. Results demonstrated no effect of set-up instructions and no interaction (*ps* > .05). However, a main effect of ladder height was observed.

In general, as ladder height increased, participants preferred a more shallow angle compared to the angle they produced when following the instructions. The deviation for the 5.2-meter ladder (m = 6.4 degrees, SD = 6.0) was significantly larger than the deviation for either the 3.0-meter (m = 3.99, SD = 3.96) or 4.3-meter ladder lengths (m = 4.79, SD = 6.89). This finding is an additional indication that what "looks and feels" correct to an unaided user is generally more shallow than both the recommended 75.5 degrees and the somewhat more shallow angles produced by the instructions and aids evaluated in this study.

GENERAL DISCUSSION

These results suggest that some instruction and aid in the set-up of a ladder can produce angles that more closely approximate the suggested value of 75.5 degrees. What is unknown (and unanswered in this study) is the objective significance of this 75.5 degree recommendation—it is unclear whether this is really the benchmark by which people's behavior should be judged. Moreover, it is unclear how large a deviation from this 75.5 degree figure is significant from a practical, and not a statistical, standpoint. Further empirical research is clearly needed to substantiate the 75.5-degree figure and to define the acceptable level of deviation from that figure.

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