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Evaluation of postural sway and impact forces during ingress and egress of scissor lifts at elevations

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Workers are at risk when entering (ingress) or exiting (egress) elevated scissor lifts. In this study, we recorded ground impact forces and postural sway from 22 construction workers while they performed ingress and egress between a scissor lift and an adjacent work surface with varying conditions: lift opening designs, horizontal and vertical gaps, and sloped work surfaces. We observed higher peak ground shear forces when using a bar-and-chain opening, with larger horizontal gap, with the lift surface more than 0.2 m below the work surface, and presence of a sloped (26°) work surface. Similar trends were observed for postural sway, except that the influence of vertical distance was not significant. To reduce slip/trip/fall risk and postural sway of workers while ingress or egress of an elevated scissor lift, we suggest scissor lifts be equipped with a gate-type opening instead of a bar-and-chain design. We also suggest the lift surface be placed no more than 0.2 m lower than the work surface and the horizontal gap between lift and work surfaces be as small as possible. Selecting a non-sloped surface to ingress or egress a scissor lift is also preferred to reduce risk.

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1. Introduction

Scissor lifts (Fig. 1) are commonly found at many construction sites, and when used properly they can facilitate completion of many construction tasks. Over the past decade, the use of scissor lifts has increased significantly in industries such as construction, telecommunication, and warehousing and storage. Their growing popularity makes scissor lift safety an important issue. The scaffolding industry has long recognized fall hazards associated with work on scissor lifts (Burkart et al., 2004; Heath, 2006; McCann, 2003). A study of the Census of Fatal Occupational Injuries (CFOI) data found that falls from vertical lifts accounted for 44% of vertical-lift deaths, almost all involving scissor lifts (McCann, 2003). A later study conducted by the National Institute for Occupational Safety and Health (NIOSH) confirmed the increasing trend for fatalities associated with falls from scissor lifts and further identified that extensibility factors—the extended height of the lift or the vertical position of the worker—were significant contributing factors to 72% of scissor lift fatalities (Pan et al., 2007).

Scissor lifts are available that can reach between 6 and 15 m (20 and 50 ft). At such heights, the stability of the lift and worker are of great concern. According to the recent draft version of American National Standards Institute (ANSI) *A10.29* (2012), workers may enter and exit scissor lifts at heights greater than 1.8 m (6 ft) when the lift platform surface is adjacent to the elevated surface. The standard further specifies that if the lift platform is adjacent to the elevated surface, there shall not be a vertical gap larger than 0.2 m (8 inches) or a horizontal gap larger than 0.35 m (14 inches) between the lift platform and the adjacent surface. To date, there has been no scientific study on the manner in which the vertical and horizontal gaps were determined and how the distances between the lift platform and the adjacent surface may affect each worker's postural stability. In practice, scissor lifts are sometimes positioned at a vertical distance greater than that recommended by the ANSI standard (0.2 m or 8 inches).

Uneven surfaces can increase the risk of falling, especially during ingress and egress actions. Two types of uneven surfaces are typically encountered during the ingress and egress of a scissor lift.

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Fig. 1. A demonstration of the structure of scissor lifts (reprinted with permission of Skyjack Inc.).

One is the difference in elevation between the lift platform and the adjacent work surface; namely, the work surface is either higher or lower than the platform of the scissor lift. The second type of uneven surface is an inclined surface; namely, the adjacent work surface is sloped compared to the platform of the scissor lift. Both conditions can introduce significant safety concerns for the use of scissor lifts. First of all, a difference in surface elevation significantly increases the risk of slip and trip (Brauer, 2006). Second, a decided or large difference in surface elevations could significantly increase trunk instability and alter ground impact forces during worker foot contact (landing), which also increases the risk of falling (Fathallah and Cotnam, 1998, 2000). An inclined work surface introduces a higher risk of slipping due to increased ground shear forces and reduced ground compression forces (Zhao et al., 1987). Previous studies have shown that standing on inclined surfaces could reduce standing stability (Bhattacharya et al., 2002/2003; Lin and Nussbaum, 2012; Simeonov et al., 2003, 2009) and may cause changes to body postures and lower extremity biomechanics (Mezzarane and Kohn, 2007; Sasagawa et al., 2009). When walking on inclined surfaces, the pattern of walking as well as lower extremity biomechanics will also be altered (in comparison to walking on flat ground) in order to compensate for the increased risk of slip and fall (Leroux et al., 2002; McIntosh et al., 2006). Finally, when performing manual tasks (such as trunk bending and lifting) on inclined surfaces, previous studies have observed altered and unbalanced trunk biomechanical responses (Bhattacharya et al., 2002/2003; Hu et al., 2013, 2016; Jiang et al., 2005), increased magnitude of spinal loading (Shin and Mirka, 2004), and reduced trunk stability (Wade and Davis, 2009) among testing participants. These conclusions are consistent with the high incidence rate of fall-related fatal and nonfatal injuries reported in the roofing industry (Wade and Davis, 2005).

Additionally, there is a lack of quantitative data to demonstrate that potential risks may be associated with improper ingress and egress techniques, especially at heights. Measuring sway and other measures of postural instability at heights is difficult (Bain and Marklin, 2012). This is the first study in the literature to evaluate postural sway, effect of inclined surface, and impact force during ingress/egress to an elevated device—a scissor lift. This study also demonstrates how advanced experimental design can be used to develop scientific hypotheses, and responds to numerous requests from an industry-wide standards committee (i.e., ANSI A10.29) for methods that involve the safe use of a scissor lift.

The objective of this study was to evaluate postural sway and impact forces during various methods of ingress and egress scissor lifts at elevation. The first part of the study examined the effects of vertical and horizontal gaps between the lift platform and the adjacent surface on each worker's postural sway. These were evaluated on two types of scissor lift ingress/egress systems, known as “gate” and “bar and chain” designs. The gate design simply had subjects push a gate open to step onto the platform, whereas the bar and chain design challenged subjects to unhook the chain and bend laterally to pass a top rail while stepping toward the platform (Fig. 2(a)-(b)). The second part of the study focused on the effect of an inclined landing surface. The hypothesis was that the maximum interaction forces between human participants and landing surfaces resulting from various ingress/egress conditions are different and such differences can affect workers' postural sway at elevations and on inclined surfaces.

2. Methods

2.1. Participants

Twenty-two male construction workers, mean age of 28.5 ± 10.7 years, who had at least 1 year of experience working with scissor lifts were recruited from northern West Virginia. Their mean body weight was 82.8 ± 3.3 kg (182.5 ± 7.4 lbs), and mean body height was 1.82 ± 0.08 m (6.0 ± 0.29 ft). All participants completed a health-history screening before participating in the study to ensure they were free of a history of dizziness, tremor, vestibular disorders, neurological disorders, diabetes, chronic back pain, and falls within the past year resulting in injury with days away from work. Each participant gave informed consent according to the procedures approved by the NIOSH Institutional Review Board.

2.2. Laboratory setup

A commercially available 5.79 m (19 ft) electric scissor lift (Model SJIIIE 3219, Skyjack, Inc, Ontario, Canada) was used for the study. The SJIIIE 3219 scissor lift platform has a deck extension, a gate for ingress and egress, guardrails around its periphery, as well as toeboards on all sides (Fig. 1). This lift platform has a length and a width of approximately 0.73 and 1.6 m (29 and 64 inches), respectively, and a deck to extend overall length to approximately 2.54 m (100 inches). The guardrails, composed of a toprail and a midrail, have a height of 0.99 m (39 inches). The toeboard is about 0.15 m (6 inches) high. This type of scissor lift has a total load-bearing capacity of 249.4 kg (550 lbs). The separate rated load-bearing capacity on the main lift platform and 0.9-m (3-ft) deck are 113.3 and 136.0 kg (250 and 300 lbs), respectively. These specifications conform to ANSI standard A92.6 for Self-Propelled Elevating Work Platforms.

A test structure (Fig. 3(a) and (b)) was constructed to house measurement devices for capturing force data related to foot pressure from participants egress the aerial lift. This structure was designed to duplicate conditions found in worksites to be accessed by scissor lifts and served to capture force data typical of that found