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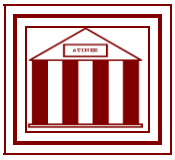

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Does Wearing a Smoke Hood Impede one's Ability to see Stairs while Descending?

Rong Huangfu
PhD Student
Auburn University
USA

Conner Lusk
MSc Student
Auburn University
USA

Leslie Gunter
PhD Student
Auburn University
USA

Jerry Davis
Associate Professor
Auburn University
USA

Yousif Abulhassan
Assistant Professor
Murray State University
USA

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Athens Institute for Education and Research
8 Valaoritou Street, Kolonaki, 10671 Athens, Greece
Tel: + 30 210 3634210 Fax: + 30 210 3634209 Email: info@atiner.gr URL: www.atiner.gr
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Does Wearing a Smoke Hood Impede one's Ability to see Stairs while Descending?

Rong Huangfu

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Abstract

Seeing where one is stepping is critically important when descending stairs. This study evaluated three (3) commercially available smoke hoods (A, B & C) in the context of vision restriction once donned. Subjects (N=16) were randomly tested with and without (control) smoke hoods for their vertical visual 'field of view' in a stairwell. Neck and trunk flexion angles were measured using an IMU based motion capture system (Xsens). When standing erect at the top of a staircase (descending) without a smoke hood, all subjects could see the immediate stair tread they would step down upon using only neck flexion. Conversely, while wearing a smokehood, 75% of the subjects experienced a reduction in the number of stair treads they could see, ranging between 1to 3 treads obscured. Paired t-Test demonstrated that the number(s) of stairs that could not be seen were significantly different compared with the control (p-value of 0.034, 0.001 and 0.004 for smoke hoods A, B, and C respectively). Those subjects who could not see the immediate stair tread while wearing a smoke hood, were further instructed to bend their trunk to help them see the immediate stair, while maintaining their neck fully flexed. Trunk flexion angles were 14.1˚ (SD=7.0), 13.8˚ (SD=8.8) and 13.4˚ (SD=7.4) for smoke hoods A, B and C respectively. The combined effect of neck and trunk flexion shifts the subjects' center of mass (forward) towards the direction of decent, potentially increasing risk for a fall during stairwell egress.

Keywords: Evacuation, IMU, Motion Capture, Smoke Hoods, Stairs.

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Introduction

Fifteen thousand seven hundred (15,700) fires are reported annually in United States high-rise buildings, contributing to 53 deaths, 546 injured, and $235 million in direct property damage (Hall Jr, 2013). High-rise building fires are considered especially dangerous due to the potentially high number of occupants involved (Ronchi and Nilsson, 2013).

The traditional method to evacuate high-rise buildings in case of emergency is by stairwells. Several studies have been performed to investigate factors that impact stairwell evacuation, such as the design of the stairs (Pauls, 2002; Pauls et al., 2007), the behavioral aspectsof evacuees (Boyce et al., 2012), the effect of merging streams (Galea et al., 2008), and evacuee fatigue (Averill et al., 2005; Galea et al., 2010). Other studies that evaluated occupant movement in building evacuation have also been review and summarized (Peacock et al., 2010).

Most fire deaths are not caused by burns, but by smoke inhalation. Often smoke incapacitates so quickly that people are overcome and cannot make it to an otherwise accessible exit. Personal protective equipment such as a smoke hood is therefore critical to ensuring a sufficient respirable air to allow building occupants enough time to evacuate safely via available exits. In tall buildings, this usually involves egress via stairwells. Many aspects of evacuation associated with smoke hoods have not been well established to date. Specifically, there is a lack of knowledge in how wearing a smoke hood might affect stair well evacuation time. The purpose of this study was to evaluate the effects of wearing smoke hoods with three different designs potentially impacting vision (field-of-view).

Method

Nine (9) male and seven (7) female (N=16) college aged students(mean age = 24.0±2.8 years; range 19-30) were recruited to participate in the study. Subject demographics, stature and segmental limb length were collected. This study was performed as a part of a graduate level safety engineering course, and was approved by the Auburn University (AL, USA) Institutional Review Board (IRB).

Smoke Hoods

Smoke hoods protection generally consist of a head cover that seals the breathing area, a filter for against toxic gases (HCL,SO_2, HCN, and CO) and a transparent cover that allow vision. There are several different designs of smoke hood available in the market. In this study, three prevalent smoke hoods with varying level of potential vision obstruction were chosen for testing (Figure 1).

Figure 1. *Designs of Tested Smoke Hood (Type A, B, C)*

Source: www.panindochina.com.vn; www.spezial-depot.de; nodis.en.ec21.com.

Detailed information for three tested smoke hoods is provided in Table 1.

Table 1. *Smoke Hood Information (A, B and C)*

Name	Brand	Manufacture Date	Certified Standard	ID
Smoke/Fire HoodMask	iEvac	June 2016	ASTM E2952-14	A
Escape Hood SR 77-2	Sundstrom	Dec. 2015	EN 403:2004 EN 14387	B
LifeKeeper	Nodis	May 2016	ANSI 110	C

These three type of smoke hoods are certified under different standards, but all specifically related to air-purifying/filtering respiratory protective smoke escape devices.

- ASTM E2952-14: Standard Specification for Air-Purifying Respiratory Protective Smoke Escape Devices (American Section of the International Association for Testing Materials (ASTM International, 2014).
- EN 403:2004: Respiratory protective devices for self-rescue - Filtering devices with hood for escape from fire - Requirements, testing, marking (European Committee for Standardization-CEN, 2004).
- EN 14387: Respiratory protective devices - Gas filter(s) and combined filter(s) - Requirements, testing, marking (CEN, 2004).
- ANSI 110: American National Standard for Air-Purifying Respiratory Protective Smoke Escape Devices (American National Standards Institute-ANSI, 2009).

Motion Capture System

A commercially available inertial sensor-basedmotion analysis system, the Xsens MVN BIOMECH system (Xsens Technologies BV, Enschede, Netherlands) (Roetenberg et al., 2009) was used to measure trunk and neck flexion. The technology consists of a whole-body kinematic measurement system consisting of 17 sensors designed to measure and record movement

of the major segments of the human body (forearm, upper arm, trunk, etc.). Five sensors were used (head, left shoulder, right shoulder, sternum and pelvis) in this study to measure neck and trunk movement when wearing a smoke hood compared to the contrasted condition. Anthropometric data were collected to create a rigid link biomechanical model along with the information collected from the sensors. The output of this biomechanical model is a simulated estimation of the human motion, which was used to calculate neck and trunk flexion in this study.

Experiment Procedure

The fundamental question being addressed was whether wearing a smoke hood reduced one's vision (the ability to see fewer stair treads directly in front of the subject).

1) Five (5) motion capture sensors were attached to the subject and initial calibration was performed.
2) Subjects were affixed to an immobilizing device which stood securely on a landing atop a staircase (center panel in Figure 2). A randomized number set was placed on each stair tread in front of the subject (left panel in Figure 2).
3) Based on randomized sequence (type A, B, C smoke hood and no smoke hood) subjects were assigned the order of treatments.
4) Subjects were asked to identify which random number (left panel in Figure 2), de facto stair tread, they could fully see before/after fully flexing (bending) their neck (Figure 3). The number of stair treads (directly in front and closest to them) that subjects *could not see* and their neck flexion angles were recorded.
5) If subjects were not able to see the closest tread with fully flexing their neck, they were instructed to slowly bend their trunk while maintaining the fully flexed neck until they could see the closest tread. The trunk flexion angles were recorded.

Figure 2. *Vision (Field-of-View)*

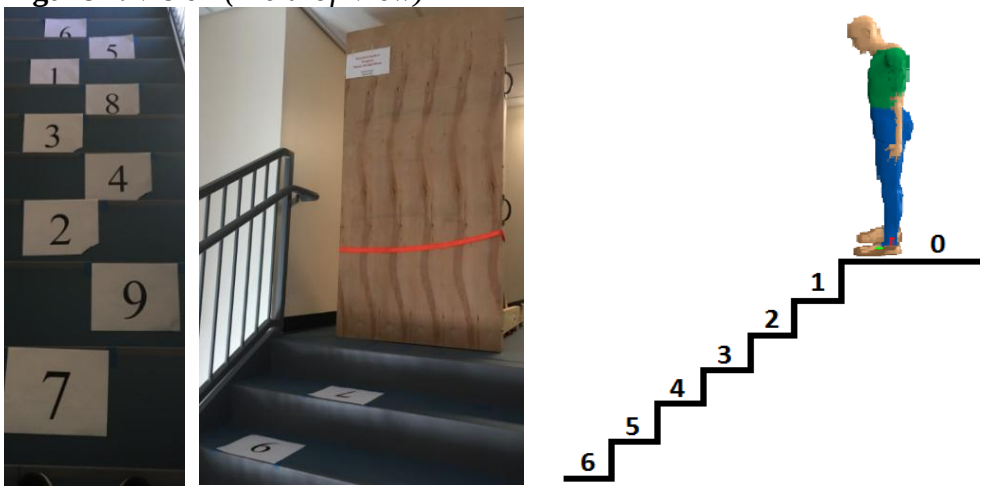


Figure 3. *Subject with/without the Smoke Hood*

Type A: iEvac® Smoke/Fire Hood

Type C: Nodis® LifeKeeper

Type B: Sundstrom® Escape Hood SR 77-2

Without Smoke Hood

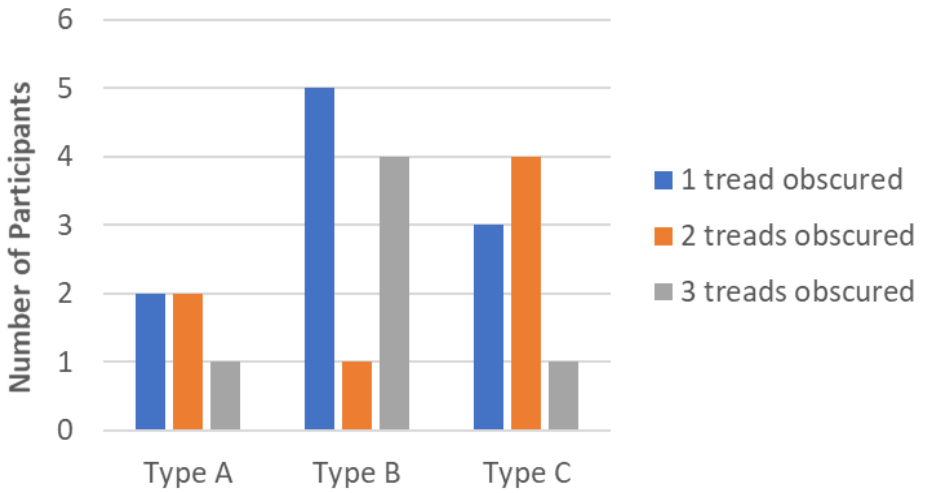
Paired t-Testswere performed to evaluate the effects of the smoke hood on vision (field-of-view) and maximum neck flexion angle.

Results

Neck flexion angles between the control group (no smoke hood) and each type of smoke hood were not significant, with P-value of 0.383, 0.320 and 0.446 (Paired t-Test) of smoke hood type A, B and C respectively. This suggests that the smoke hoods tested in this study did not impact the neck flexion capability of the participants.

All sixteen (16) subjects reported being able to see all the treads on the descending staircase directly in front of them when not wearing the smoke hood. Conversely, 75% of the subjects experienced a reduction in the number of stair treads they could see, ranging between 1 to 3 treads obscured (Figure 4), when wearing a smoke hood.

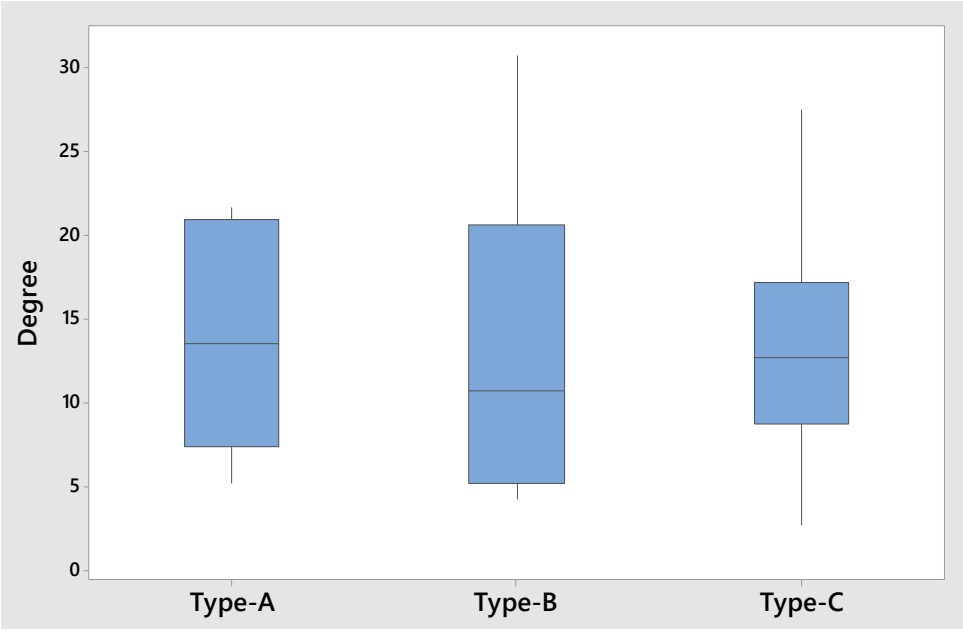
Figure 4. *Vision (Field-of-View) of the Subjects when Wearing Smoke Hood*



Paired t-Tests showed that the number(s) of stairs that could not be seen were significantly different compared with the control (p-value of 0.034, 0.001 and 0.004 for smoke hoods A, B, and C respectively). No significant differences were found between each type of smoke hood.

Participants who could not see the first stair when wearing a smoke hood, were instructed to bend their trunk to help them to see the first stair while maintaining their neck fully flexed. The trunk flexion angles were 14.1 (SD=7.0), 13.8 (SD=8.8) and 13.4 (SD=7.4) for type A, B and C respectively (Figure 5).

Figure 5. *Trunk Flexion Angles*



Discussion

Studies and/or simulation models exist that evaluate different factors that potentially affect stairwell evacuation time. However, personal protective equipment that may be worn by evacuees has generally not been considered in these studies or models. In high-rise buildings, the necessity of wearing smoke hoods to ensure a safe atmosphere during the evacuation process is likely since it may take greater than ten (10) minutes to evacuate from a 50-floor (plus) building. Therefore, it is important to understand how different designs of smoke hoods may impact vision when descending stairs. Based on the results of this study, wearing a smoke hood (three types of smoke hood tested in this study) results in a reduction of vision, which required bending forward to compensate for this vision reduction. As a result, this may suggest subjects need a higher level of concentration to successfully locate and step on the next tread, leading to increased fatigue and potentially increasing evacuation time. In addition, the combined effect of neck and trunk flexion shifts the subjects' center of mass forward towards the direction of decent, potentially increasing the risk for a fall during stairwell egress. This reduced vision may come from the air filter located directly in front of the face or the relative movement of the smoke hood when bending one's neck. Improved smoke hood design that considers the impact of vision is warranted.

Limitations

The following study limitations are acknowledged:

1) Static measurement without the dynamic component of descending stars.
2) No level of subject concern or fear was present during testing.
3) Limited sample size (N=16).

Conclusions

All three designs of smoke hoods impacted the wearers' vision (field-of-view) while being used, resulting in alternate postural strategies to compensate for this effect. This additional trunk and neck flexion suggest increased instability while descending, requiring more attention and effort for evacuees to locate, position, and balance themselves during decent, and may result in longer evacuation times. Smoke hood designers, manufacturers, and those procuring smoke hoods for high rise buildings should consider all available models and consider the potential impact of vision (field-of-view) obstructions based on the design of the smoke hood itself.

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