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Empirical measurement and improvement of hazard recognition skill

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ABSTRACT

One explanation for high injury rates and the recent plateau in construction safety performance is that workers remain unable to recognize and manage hazards in dynamic and transient construction environments. This notion is supported by recent experimental studies, which revealed that workers are typically unable to identify and manage over 55% of hazards in their immediate work environment. These alarming discoveries prompted a series of multiple baseline experiments that tested three interventions thought to improve hazard recognition. In these studies, data were gathered from over 3000 h of field observations with 103 workers and hazard recognition performance was measured before and after each intervention was introduced. All three interventions caused improvement in overall hazard recognition performance; however, each intervention's impact on the recognition of specific types of hazards was not evaluated. This paper addresses this knowledge gap by presenting and in-depth analysis of these data that: (1) elucidates micro-level hazard recognition across different hazard types and categories and (2) evaluates the hazard-specific impact of three recently developed interventions. The results reveal that gravity, motion, mechanical, and electrical hazards are associated with the highest baseline hazard recognition levels; whereas temperature, chemical, radiation, and biological hazards were the least recognized hazards in both the baseline and post-intervention phases. This suggests the need for targeted hazard recognition programs that focus on energy sources that are commonly missed.

1. Introduction

Every year over 60,000 fatal injuries are reported from construction projects around the world (Lingard, 2013). In 2012 the US construction sector accounted for 19% of fatal injuries, while only employing 4% of the national workforce (Bureau of Labor Statistics, 2013). According to Carter and Smith (2006) construction workers are two times more likely to suffer serious injury and five times more likely to be killed on-the-job that the average worker. Given these alarming statistics, researchers have devoted much time and effort toward identifying, examining, and understanding factors that contribute to construction incidents. Among these, the impact of hazard recognition and situational awareness on injury prevention has been emphasized. For example, Haslam et al. (2005) reviewed construction accident reports and found that 42% of incidents were linked with inadequate hazard recognition or appraisal. Additionally, Albert et al. (2014a) and Carter and Smith (2006) found that, when hazards are not adequately identified, it is impossible for workers or managers to implement effective and responsive hazard management strategies to mitigate accident potential.

Despite the significance of hazard recognition, recent research has revealed that construction workers and managers are unable to identify over half of hazards in their immediate work environment (Albert et al., 2013, 2014a, 2014b). Similarly, studies conducted by Bahn (2013) in Australia revealed that novice workers were unable to recognize 57% of occupational hazards; and studies in the U.K. revealed that between 10 and 33.5% of hazards were not adequately identified or assessed in practice (Carter and Smith, 2006).

When construction workers are unable to recognize hazards, the likelihood of catastrophic incidents increases because situational awareness is severely compromised (Carter and Smith, 2006), and the ability of workers to respond to hazardous stimuli decreases dramatically (Albert et al., 2014a). To prevent such undesirable outcomes, and as required by regulatory bodies, employers adopt a wide array of interventions to improve hazard recognition

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skill. Unfortunately, existing hazard recognition training strategies, such as presentations on relevant regulations, are only marginally effective. Organizations using such methods have work crews that identify and document fewer than half of the hazards they face in a given work period (Bahn, 2013; Albert et al., 2013).

2. Definitions, epistimological positions, and research questions

The word *hazard* is defined by Merriam-Webster (2015), simply as "a source of danger." Consistent with previous research on energy-based hazard recognition (Haddon, 1970), we defined hazards more specifically as a source of energy that, if released and results in exposure, could cause injury or death. From a pure physics perspective energy is required to do work. In an occupational setting, energy is required to lift, transport, and assemble materials, which is stored or transferred by hoists, cranes, equipment, tools, and even the workers themselves. Additionally, some materials possess stored energy in their natural state, which may be released in the act of performing work (e.g., excavating a trench or installing a cofferdam). Although impossible to describe all potential sources of energy, our position is that energy is ubiquitous in occupational environments. Additionally, the knowledge that hazards exist and involve transfer of energy in the trajectory of an injury has been empirically supported (Albert et al., 2013; Alexander et al., 2015).

Our epistemological perspective is that one's knowledge *that* hazards are sources of energy can be distinguished from the knowledge of *how* to recognize a hazard. In this paper, we focus on the latter by proposing that a person knows how to identify a particular hazard if they can successfully distinguish and communicate a problematic source or release of energy from other stimuli in the environment. Such a definition links naturally with signal detection theory, which is the ability of an individual to discern an information-bearing stimulus and noise. Also, in accordance with signal detection theory, we consider a situation where an individual correctly identifies the presence of a hazard when it actually exists a success and a situation where an individual does not identify a hazard that actually exists as an error (i.e., a miss). In this study, we do not penalize a situation where an individual identifies a hazard that does not actually exist as these false alarms are comparatively insignificant to misses in practical terms.

Hazard recognition may take many forms in an occupational scenario. For example, a worker may recognize a hazard prior to initiating work, during work, or even after the work has been completed. Distinguishing that a source of energy is present is a difficult task as energy is constant flux with objects and people being transported, lifted, lowered, and installed. The focus of this study is on the recognition of hazards prior to the initiation of work as we believe that it is in the planning stage that hazards can be best communicated and controlled. Although some studies have discussed dynamic hazard recognition that occurs during work (Albert et al., 2014a), we do not have sufficient data to draw conclusions for dynamic hazard recognition. It should also be noted that some hazards are not reasonably identifiable with human senses alone (e.g., micro-fissures in materials) and others may have not yet been discovered. Thus, we focus only on the known hazards documented in previous empirical research.

We commit to the taxonomy of hazards developed by Albert et al. (2013, 2014a, 2014b), which involves the following ten energy sources: gravity, motion, mechanical, pressure, radiation, biological, chemical, sound, electrical, and temperature.

All previous hazard recognition studies focused on *general* hazard recognition ability of workers, without specific attention to the *types* of hazards identified or overlooked. Such broad focus limits the ability to target new interventions or test novel research hypotheses. Thus, our specific research objectives were to use a large volume of hazard recognition data obtained by Albert et al. (2013, 2014a, 2014b) to answer the following research questions:

1. What is the baseline hazard recognition skill level of workers for each hazard type (e.g., gravity, motion, mechanical, electrical, etc.) before any intervention is introduced?
2. When hazard recognition improvement interventions are introduced, how is hazard recognition skill affected for each energy type?

3. Methods of hazard recognition improvement

Contractors use a wide variety of hazard recognition methods in practice. According to prevailing literature, these hazard recognition methods can be classified into two types: predictive methods and retrospective methods. Predictive methods such as job hazard analyses (JHAs) involve visualizing and predicting construction tasks with the goal of identifying associated hazards (Rozenfeld et al., 2010). Alternatively, retrospective methods such as root cause analyses and hazard checklists rely predominantly on past experience in similar work settings (Fang et al., 2004).

An examination of current hazard recognition improvement strategies reveals several critical weaknesses. For example, the scope of predictive hazard recognition methods typically fail to include hazards that are imposed by adjacent crews or new hazards that emerge as work changes during execution (Rozenfeld et al., 2010). Further, traditional methods do not capture the fact that work as planned is often different from how work is actually performed (Borys, 2012), and they are designed assuming that workers can accurately predict the flow of work tasks and are inherently skillful at identifying all task-related hazards. Similarly, retrospective hazard recognition methods (e.g. checklists) are limited because they are constructed based on past experience and injury records, which are often incomplete or inaccurate. Consequently, past injuries are often not generalizable across projects and situations (Albert et al., 2013). Because of these limitations, methods that are independent of a particular checklist or form are far superior. Fortunately, from a psychological perspective, a recent philosophy has emerged that has the potential to improve the hazard recognition skill: energy-based hazard recognition (Albert et al., 2013, 2014a, 2014b).

Based on Haddon's energy release theory (1970, 1973), Fleming (2009) suggested that undesirable exposure to energy sources in construction environments could lead to injuries and illnesses. Albert et al. (2013) further developed this theory and proposed that *all* hazards, damage, injuries, and illnesses can ultimately be traced to the unwanted release of energy. Further, they hypothesized that a taxonomy of common energy sources, if provided to workers as mnemonic cues, could enhance hazard recognition. For example, workers could use mnemonic cues such as "Gravity" (e.g. falling objects, trips and falls), "Mechanical" (rotating equipment, compressed springs and conveyers), "Electricity" (e.g. power lines, transformers and energized equipment), to increase the proportion of hazards identified before work begins. Greater discussion of this theory is available in Albert et al. (2013) and the 10 energy sources are presented in Table 2.

3.1. Emerging hazard recognition methods

To address the limitations of traditional hazard recognition methods, new and improved methods have recently been proposed, developed, and tested. For example, Rozenfeld et al. (2010) proposed a modified JHA process that is more suitable for dynamic construction operations; King Chun et al. (2012) proposed virtual environments for hazard recognition training; and Goh and