Impact of Change Blindness on Worker Hazard Identification at Jobsites

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Abstract: Due to the dynamic nature of construction sites, workers face constant changes, including changes that endanger their safety. Failing to notice significant changes to visual scenes—known as change blindness—can potentially put construction workers into harm's way. Hence, understanding the inability or failure to detect change is critical to improving worker safety. No study to date, however, has empirically examined change blindness in relation to construction safety. To address this critical knowledge gap, this study examined the effects of change types (safety-relevant or safety-irrelevant) and work experience on hazard-identification performance, with a focus on fall-related hazards. The experiment required participants (construction workers, students with experience, and students with no work experience) to detect changes between two construction scenario images that alternated repeatedly and then identify any changes. The results demonstrated that, generally, safety-relevant changes were detected significantly faster than safety-irrelevant changes, with certain types of fall hazards (e.g., unprotected edge hazards) being detected faster than other types (e.g., ladder hazards). The study also found that more experienced subjects (i.e., workers) achieved higher accuracy in detecting relevant changes, but their mean response time was significantly longer than that of students with and without experience. Collectively, these findings indicated that change blindness may influence changes in workers' situation awareness on jobsites. Demonstrating workers' susceptibility to change blindness can help raise awareness during worker trainings about how workers allocate and maintain attention. **DOI: 10.1061/(ASCE)ME.1943-5479.0000908.**

Introduction

Given the complex and dynamic nature of construction projects, construction work sites face frequent changes, many of which introduce hazards into the jobsite. The ability to detect hazards is a primary step toward working safely and avoiding occupational incidents (Hasanzadeh et al. 2017b), and the ability to detect hazards in a constantly changing environment while working is associated with safer decision making and situation awareness (Parasuraman et al. 2009)—with situation awareness defined as a function of a worker's available attentional and working memory resources to acquire, perceive, and interpret environmental information (Hasanzadeh et al. 2018). As individuals rely significantly on two complementary factors in order to obtain detailed information about their surroundings—attention (Rensink et al. 1997; Rensink 2000b; Levin et al. 2002) and visual memory (Vierck et al. 2008; Andermane et al. 2019)—when there is a change in a visual display, individuals must both notice the change and compare the updated representation with their memory of the previous image (Rensink et al. 1997). Failing to notice some changes—such as a removed hole-cover or a missing section of guardrail—may put workers' lives at risk.

When changes in visual scenes go undetected, a worker experiences what is referred to as change blindness (Durlach 2004; DiVita et al. 2004), wherein an observer has difficulty detecting relatively large changes in visual scenes if the changes occur at locations other than those where the individual is attending or during a brief visual disruption (Simons and Rensink 2005). This is commonly studied via use of the flicker paradigm, in which two images (identical, with the exception of a single difference between them) are presented in alternating fashion, separated by a brief blank screen. Change blindness has been used to examine the mechanisms of visual perception, attention, and awareness (Durlach 2004; Simons and Rensink 2005; Beanland et al. 2017), and the phenomenon has received considerable attention in various contexts such as driving (Galpin et al. 2009; Beanland et al. 2017; White and Caird 2010; Velichkovsky et al. 2002; Caird et al. 2005; Pammer et al. 2018; Gunnell et al. 2019), eyewitness testimony (Davies and Hine 2007), and real-world interactions (Simons and Levin 1998; Attwood et al. 2018). Considering that multiple hazards are present in a dynamic environment, examining attentional allocation via change blindness is important to investigate. No study, however, has empirically examined change blindness within construction safety settings, which is surprising given the potential consequences associated with missing a change in one's environment, which could prove hazardous.

The present study examined whether change blindness also impacts a worker's ability to detect changes in a construction environment, in addition to investigating individual differences that may mitigate the likelihood of detecting change. In examining these considerations, this study revealed novel insights into the human

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Table 1. Ways to introduce changes to stimuli in change-blindness studies

Event	Example	Citations
Gap-contingent	The change occurs between the original and altered stimuli after displaying a patterned mask or a simple blank screen.	Hochberg (1968), Phillips (1974), Pashler (1988), Simons (1996), Rensink et al. (1997), Hollingworth et al. (2001), and Niedeggen et al. (2001)
Saccade-contingent	The change occurs during an eye saccade.	Bridgeman et al. (1979), McConkie and Zola (1979), Carlson-Radvansky and Irwin (1995), Grimes (1996), and Henderson and Hollingworth (1999)
Shift-contingent	To create a simulated saccade, the change occurs during a sudden shift of the entire display.	Sperling (1990) and Blackmore et al. (1995)
Blink-contingent	The change occurs during an eye blink.	Kevin O'Regan et al. (2000)
Splat-contingent	The change coincides with the appearance of short distractors or splats. (Unlike other events, in this approach, the change is completely undisturbed; that is, the splats do not cover the change area).	O'Regan et al. (1999) and Rensink et al. (2000)
Occlusion-contingent	The change occurs after the stimulus is briefly occluded.	Simons and Levin (1998), Behrmann et al. (1998), and Rich and Gillam (2000)
Cut-contingent	Used commonly in movies, the changes occur during a cut between two camera positions.	Levin and Simons (1997, 2000)
Gradual	The change occurs gradually between the original and modified display.	Simons et al. (2000)

information-processing system. The results of the study cast light on why workers fail to detect changes on jobsites and what safety managers can do in order to enhance and improve workers' hazard identification.

Background

Change Detection

Change detection is defined as "the apprehension of change in the world around us" (Rensink 2002, p. 246) and is pervasive in day-to-day life. For example, detecting a change in a traffic light will influence driver behavior, and failing to detect a change in a traffic light will increase risk for the driver and others on the road. Research on change detection focuses on understanding the mechanisms by which an individual first notices a change visually. Successful change detection requires reporting on the existence (detection), essence (identification), and/or location (localization) of a change (Rensink 2002). Individuals tend to believe that they will be easily able to detect a change that occurs in front of them (Levin et al. 2000); however, empirical investigations have shown that people can fail to detect a change even if it is large, repeated, or expected (e.g., Simons and Levin 1997; Rensink 2000b).

The earliest studies on change detection can be traced back to the mid-1950s; participants were supposed to detect changes in dot patterns as a function of the number of dots and the average separation between them (French 1953). A limited number of studies designed various gap-contingent change-detection experiments—in which the changes occurred during a blank screen presented between the original and altered stimulus (e.g., Phillips 1974; Pashler 1988); other studies have used saccade-contingent change-detection experiments, in which changes occurred during an eye movement (e.g., McConkie and Zola 1979; Grimes 1996). In the mid-1990s, Simons (1996) and Rensink et al. (1997) transformed this field of study into a systematic framework to study cognitive processes (Rensink et al. 1997; Rensink 2002) by using realistic stimuli—such as images of real-world scenes or dynamic events (Simons and Levin 1998) and by examining trans-saccadic memory to better understand change blindness (Irwin 1996). Since the 1990s, change detection has evolved into a thriving and promising field of study for better understanding cognitive processes, particularly the interaction between attention and perception. This study fits within this evolving experimental space.

The basic design of change-detection experiments involves showing a stimulus (e.g., an image) to an observer, changing the stimulus (e.g., removing or altering an object in the image), and measuring the response of the observer. Rensink (2002) categorized different approaches for conducting change-detection experiments based on seven dimensions. In the following, we discuss these seven dimensions as fundamentals in designing change-detection experiments for construction safety.

Contingency of Change or Attentional Manipulation

In change-detection experiments, change can be implemented in a number of different ways. Rensink (2002) identified eight common events used in change-detection experiments, as shown in Table 1. In the present study, a gap-contingent approach was used, because it is the most common and well-established paradigm for investigating change blindness, providing a firm base for comparing the current study to the existing literature.

Repetition of Change

One attribute that may characterize successful change-detection is the number of times the change occurs. Paradigms differ with regard to the opportunity and time one has to detect a change, but the majority of investigations are constituted of either one-shot or repeated-change experiments (Fig. 1). In the one-shot paradigm, a single unexpected event occurs, and researchers primarily measure detection accuracy for that event (e.g., Levin and Simons 1997; Simons and Levin 1998). This approach is ideal for real-world experiments and for any situation in which the change is unanticipated and the

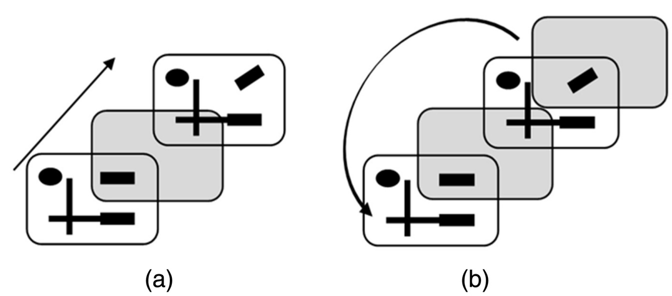


Fig. 1. One-shot and repeated change paradigm. (Adapted from Rensink 2002.)

participant is not necessarily asked to detect a change in advance. By contrast, during repeated-change experiments—also called flicker experiments—the change is repeated until the participant either detects the change or the trial time runs out. With this approach, both accuracy and response time are considered.

One critical difference between the two approaches is that the flicker paradigm involves effort and working memory processes, and performance can be altered as either of these variables is manipulated. Using the flicker paradigm, Rensink (2000c) has demonstrated that the duration of the blank flicker screen influences performance, with change detection being enhanced as flicker durations are reduced. As the duration of the blank screen decreases, the integration between the original and modified stimuli becomes stronger and changes become easier to detect (Rensink 2000c). In contrast, as the duration of the blank screen increases, so too does one's reliance on working memory processes, and the integration between the original and modified stimuli becomes weaker.

Content of Display

Another dimension of change-detection experimentation is the content of the display. In previous studies, a spectrum of options from static images to dynamic events in the real world have been used. The most basic types of displays used in previous studies were simple figures, such as dots, lines, or letters arranged in different types of geometrical (e.g., circular) arrays. Although somewhat artificial in relation to the real world, these types of carefully controlled experiments are necessary in order the isolate the study of attention/perception from other cognitive processes (Luck and Vogel 1997; Rensink 2000c; Scott-Brown et al. 2000). In order to provide greater realism without the full complexity of real-world stimuli, other researchers have used drawings of objects and/or scenes that can be as simple as arrays of line-based sketches to full-color computer renderings showing complete scenarios (Simons 1996; Henderson and Hollingworth 1999; Scholl 2000; Williams and Simons 2000). Although drawings of objects and scenes can be useful in studying change detection, some researchers have argued that drawings create an artificial parsing of a scene. To overcome this challenge, other researchers have used photographs of real-world objects (Blackmore et al. 1995; Grimes 1996; Rensink et al. 1997; Zelinsky 2001; Ro et al. 2001) or dynamic displays such as movies (Levin and Simons 1997; Gysen et al. 2002; Wallis and Bulthoff 2000). Finally, other researchers have gone one step further to achieve the highest level of realism by designing experiments using real-life interactions (Simons and Levin 1998; Frances Wang and Simons 1999). For example, in a study conducted by Simons and Levin (1998), while the experimenter was speaking with a pedestrian on a university campus, the conversation was temporarily disrupted by two people carrying a door between the experimenter and the pedestrian. Behind this barrier, the experimenter was switched out with another person who was easily distinguishable from the first; however, a large number of individuals (67%) failed to notice this change.

Content of Change

Most change manipulations involve the addition or deletion of an item, changing the properties of an item (e.g., orientation, size, shape, or color), changing the semantic identity of an item (e.g., rearranging parts of an item), changing the spatial arrangement or layout of items, or some combination of these methods (Rensink 2002). Considering that the magnitude of the change can impact participants' performance in terms of accuracy and response time (Smilek et al. 2000), the change should be neither radical nor an anomaly. Rensink et al. (1997) also stated that changes could be categorized as central and marginal based on the amount of interest the viewer has in the items undergoing change; central interests are the items most frequently mentioned by neutral observers in describing an image (presumably items critical to understanding and interpreting the image), whereas marginal interests are items not mentioned by neutral observers (presumably more peripheral details). This concept can inform investigations of occupational hazards, because during a hazard-identification task, a hazard would be the central interest in the scene while incidentals (e.g., a light post) would be a marginal interest in the scene.

Observer's Intention

The observer's intention, or the degree to which the observer expects a change, can also be manipulated in change-detection experiments in one of three ways: intentional detection, divided attention, and incidental. In the intentional approach, observers are told about an impending change and can allocate their cognitive resources to detecting it (e.g., Pashler 1988; Jiang et al. 2000; Wright et al. 2000). In the divided-attention approach (e.g., Grimes 1996; McConkie and Currie 1996), observers are asked to report any changes that occasionally occur while they are conducting a primary task that consumes their working-memory capacity (e.g., memorizing an image). Finally, in the incidental approach (e.g., Levin and Simons 1997; Rich and Gillam 2000), observers are not aware of a change in advance; rather, participants are asked to attend to a critical stimulus, and after the experiment they are asked whether they detected any changes during the experiment. For example, Levin and Simons (1997) asked participants to watch a video in which changes were made across multiple cuts of a filmed scene. Participants were not forewarned of the changes. Although participants were instructed to pay close attention to the video, a considerable number of changes remained undetected.

Type of Task/Response

Considering that change can be manipulated in a number of different ways, observers can be asked to conduct three interlinked but distinct types of tasks: detection (noticing the presence of a change in the display), localization (noticing the location of a change), and identification (noticing the identity of a changing item) (Rensink 2002). Detection tasks (e.g., appearance and disappearance of objects) usually require observers to detect any change in briefly displayed arrays of figures, letters, patterns, or real-world scenes (McConkie and Currie 1996; Rensink et al. 1997; Scott-Brown et al. 2000). In a localization task, Smilek et al. (2000) used printed digits and letters as stimuli, and participants were expected to specify column and row numbers associated with the location of the changed item. Similarly, Scott-Brown and Orbach (1998) used cueing patterns (i.e., contrasting spots whose positions matched that of the element that changed) to investigate whether subjects detected the location of the changing area. Typically, identification is the most difficult task, because it requires the observer not only to see the change but also to identify the type of change. Examples of identification tasks include arrays of elements subjected to luminance changes (Brawn and Snowden 1999) and color changes to objects in naturalistic scenes (Mondy and Coltheart 2000).

There are four main types of responses in change blindness experiments: explicit, semiexplicit, implicit, and visuomotor (Rensink 2002). The most common of these are explicit responses; whenever observers see a change (i.e., have a conscious visual experience), they can notify the experimenter. For example, participants are often instructed to press a key when they detect a change and to verbally describe the change (Simons 1996; Rensink et al. 1997; Jiang et al. 2000). Semi explicit responses are similar, but the observer does not need to explicitly see a change or say what the change looks like; instead, the mere feeling or sense of awareness of a change is enough to trigger a response. This type of response includes responding by pressing a key twice—first when there is a sense of a change (without seeing the change), and second when the change is detected (e.g., Rensink 2004, 2000b).

In a clear departure from the first two types of responses, an implicit response refers to the degree to which the unconscious perception of a change can impact the conscious behavior of or a decision made by the observer. In other words, the perception of change is measured by its impact on other processes. For example, Thornton and Fernandez-Duque (2000) had participants guess the type of change that was occurring in trials in which they reported not having detected a change. The results of this study revealed that correct responses in forced choice conditions were above chance levels, signifying the possibility of change detection without the awareness of change. Finally, a visuomotor response is determined by a visually guided motor system's reaction to a change (e.g., manual pointing or eye fixation) in the absence of a conscious perception of the change (Rensink 2004).

Cognitive Processes and Change Detection

Various studies have investigated the relationship between attention and change detection (e.g., Rensink et al. 1997; Simons and Levin 1997; Rensink 2000c; Aginsky and Tarr 2000; Smilek et al. 2000; Simons 2000). For example, Rensink et al. (1997) found that observers detect objects of interest to them (i.e., central interests) faster than less important objects (i.e., marginal interests), suggesting that objects of interest receive more attention and are more likely to be detected. To further validate these findings, Rensink used verbal cues in the same experiment, and this facilitated change detection. In a more dynamic setting, Levin and Simons (1997) used motion pictures to examine the ability of participants to detect changes to attended objects in which a single actor performed an act first but was later replaced by a different actor. Although the actors were the center of attention and easily distinguishable from one another, only 33% of the participants noticed the change, suggesting that focused attention is needed to detect changes.

Change Blindness versus Inattentional Blindness

Change blindness is also related to the concept of inattentional blindness, which is a separate but quite similar phenomenon. Inattentional blindness refers to a failure to detect an unexpected but visible item in a display (Jensen et al. 2011), whereas change blindness is the inability to detect changes between stimuli. Inattentional blindness is the failure to detect an unexpected yet salient event or item when engaged in a different task (i.e., when attention is directed elsewhere). An example of inattentional blindness was given by Simons and Chabris (1999) in which people failed to notice a person in a gorilla suit walking through two sets of individuals who were passing a basketball back and forth between them in a variety of ways. When participants were asked to keep track of the various types of passes thrown, they often failed to see the gorilla, but if they just watched the video, they saw it clearly and immediately (i.e., the gorilla). As an extension of this experiment, an image of a gorilla was put into an x-ray by Drew et al. (2013) when a group of radiologists performed a lung-nodule detection task. Most of the radiologists (83%) failed to detect the gorilla. The results showed that individuals may miss the occurrence of an unexpected yet salient event if they are focused on a different task (in this case, looking for a lung nodule). Collectively, the research suggests that focused attention is critical to perception, because changes and unexpected events do not seem to be perceived unless they are attended to at the correct moment in time, without other cognitive burdens.

Although change blindness and inattentional blindness are similar, experiments designed to study these two phenomena can be quite different and vary by task type and the expectations of the observer (Rensink 2000a). Inattentional blindness studies focus on the perception of unchanging information (with a greater focus on a secondary task), whereas change blindness incorporates changes that can require access to additional cognitive processes (e.g., working memory). Moreover, in change blindness studies, change is usually expected to occur, and observers try to focus their attention on the changing object or region. Inversely, in inattentional blindness, attention is diverted elsewhere by making the observers perform an additional task that requires attention; in other words, the subject does not necessarily expect change (e.g., Kevin O'Regan et al. 2000; Vierck and Kiesel 2008). The implications of these two types of blindness are manifested when individuals are involved in demanding tasks; limited attentional resources may cause salient stimuli to remain unnoticed even when the changes are right in front of an observer's eyes. Despite the similarities between change blindness and inattentional blindness, the focus of the present experiment was change blindness, given the continuous changes that may occur in the visual environment on a dynamic construction site.

Point of Departure

Previous studies have mainly examined how attentional failures may result in change blindness (Liao and Chiang 2016), improper division of attention (Dzeng et al. 2016; Hasanzadeh et al. 2017a), and lack of situation awareness (Hasanzadeh et al. 2018). Because construction activities are demanding, understanding the limited attentional capacity of humans and how attentional failures may result in human error is critical. In order to work safely, workers must process visual cues efficiently, identify potential and active hazards, detect changes, and remain situationally aware while completing their assigned tasks (Liao and Chiang 2016; Chen et al. 2016; Hasanzadeh et al. 2017c, 2018). High-risk, relevant changes on jobsites demand greater attention, accurate interpretations, and more timely responses.

Failure to see such high-risk, relevant changes can potentially put construction workers in harm's way. Change blindness has not been explored in the construction industry previously, but the paradigm affords us the opportunity to better understand failures of attention/perception. Generally, investigating change blindness has implications for understanding how workers construct, link, and store the visual representation of changes at jobsites. Previous studies on change blindness have clearly demonstrated the existence of this phenomenon and its impact on mostly mundane tasks; however, there has been no empirical study of the change blindness phenomenon within construction safety settings, in which failures of attention may have life-or-death consequences.

Because change detection performance depends on the proper allocation of attention in order to detect, identify, and localize changes (Rensink 2002; Batchelder et al. 2003), the current study examined the impacts of two types of changes (i.e., safety-relevant and safety-irrelevant changes) within the context of five types of fall hazards (i.e., elevated platforms; unprotected edges; uncovered openings; ladders; and fall-arrest systems) on change detection and fall-hazard identification. Furthermore, previous studies have demonstrated that workers' search strategies and attentional patterns while exposed to or seeing hazardous situations are impacted by their work experience (e.g., Dzeng et al. 2016; Hasanzadeh et al. 2017a; Choudhry and Fang 2008; Chi et al. 2005). The impact of experience on efficient search strategies and change detection performance has also been examined extensively in driving studies (e.g., Mueller and Trick 2013; Zhao et al. 2014; Pammer et al. 2018), with experience influencing change detection performance. Therefore, the present study examined change blindness within the construction industry to resolve the following hypotheses:

Null Hypothesis I: Participants' ability to detect various fall-hazard changes at jobsites (in terms of percent accuracy and mean response time) does not depend on the types of change (i.e., safety-relevant versus safety-irrelevant changes).

Null Hypothesis II: Participants' ability to detect various fall-hazard changes at jobsites (in terms of percent accuracy and mean response time) does not depend on the types of fall risks.

Null Hypothesis III: Participants' ability to detect various fall-hazard changes at jobsites (in terms of percent accuracy and mean response time) does not depend on the subjects' level of construction work experience.

This study used a repeated-change paradigm to test these hypotheses and to limit the scope of the study; specifically, we only investigated the change blindness phenomenon as it related to fall hazards, which are the most frequent cause of fatalities in the construction industry (Dong et al. 2013).

Research Methods

The general procedure, data collection, and analysis processes are shown in Fig. 2 and are described in subsequent subsections.

Planning and Experimental Design

The research team selected 30 images from a pool of 150 images obtained from the safety managers of the Construction Industry Institute (CII). To select images pertaining to fall hazards, five safety managers—each with more than 10 years of experience in construction—pointed out the types of fall hazards involved in each image. Using photo-editing software (Photoshop version CC 2017), the scenario images were edited to include changes among five safety-relevant objects (unprotected edges, fall-arrest systems, elevated platforms, ladders, unprotected openings) and various safety-irrelevant objects (e.g., sticker on windows, logo on machinery) across construction environments. These changes addressed the following concerns.

Repetition of Change

This study used a repeated-change (flicker) experiment, because the research team wanted to measure speed of detection as an indicator of performance in addition to accuracy (it is quite possible that response time may be impacted by a number of individual difference variables, including job experience). As mentioned

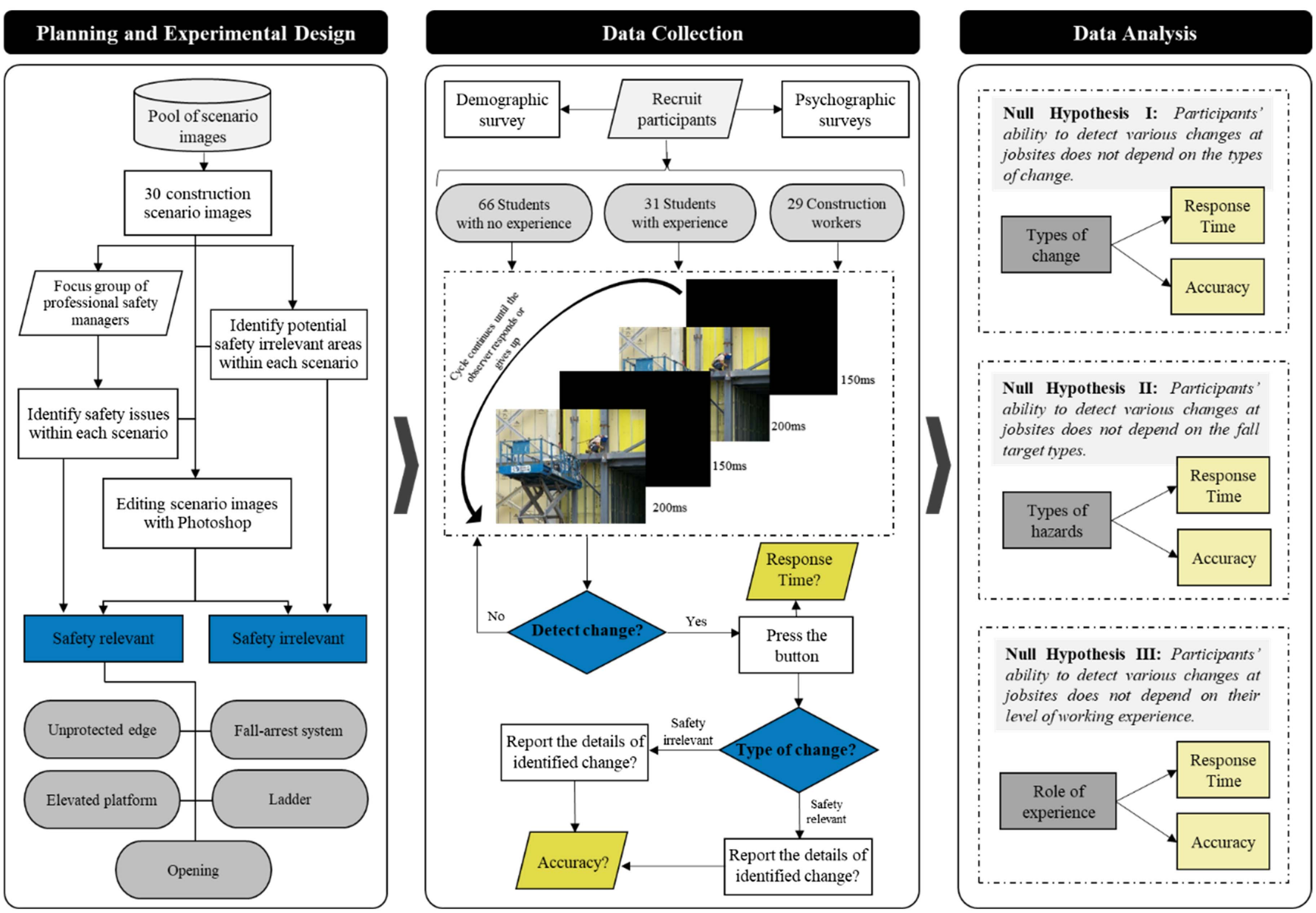


Fig. 2. Research framework for studying change blindness in construction-safety settings. (Images courtesy of David Ausmus.)

previously, Rensink (2000c) found that when the duration of the blank screen was less than 80 ms, changes were easily noticed, and when the blank screen was displayed for more than 320 ms, changes were difficult to see. Therefore, this study used a blank flicker screen with a duration of 150 ms between the two alternating images (each presented for 200 ms).

Content of Display

Photographs of real-world objects can provide a greater degree of realism than artificial parsing of a scene. Moreover, images provide a realistic depiction of common scenes that may be observed on a construction site, and using static images affords greater experimental control relative to trying to examine change blindness in the field. Therefore, in the present study, experimental stimuli included 30 images depicting jobsite scenes from both residential and commercial construction sites across the United States. These images included different types of activities, such as site work, roofing, lifting materials, finishing, erecting structures, and painting. In addition, the images included different types of fall hazards that are among the most typical safety risks leading to accidents, such as falls to a lower level, fall-protection systems, and ladder-related falls. The selected images were of high quality (1,024 × 768 pixels), and each had at least one hazard that could be identified. A focus group consisting of five safety managers who had at least 10 years of experience in residential and commercial projects independently reviewed and discussed the original pictures used in Hasanzadeh et al. (2017a) in order to identify hazards in each image, calculating the risk perceived by indicating the frequency and severity of injuries. The identified hazards were used to define safety-relevant changes.

Content of Change

In this study, the research team decided to remove a single item from each image without changing the property or identity of the changing object. If the change made to an image was different in terms of content or an anomaly was caused by the alteration, the performance of the subject could be influenced by the anomaly itself (e.g., a worker is flying) rather than by the change per se. Hence, by maintaining uniformity in the content (i.e., by removing only one item without changing its location or identity), the results could be compared without introducing any confounding factors. All changes in the images were implemented to a single structure in the images such that the images were identical except for one changing object, which appeared and disappeared on the display screen. It was also important to introduce two types of changes in order to better determine the role of experience and task-relevance on performance: safety-relevant and safety-irrelevant changes. The safety-related changes (15 trials) focused on workers or objects that were related to fall hazards, whereas the safety-irrelevant changes (15 trials) were objects that were not associated with fall hazards or did not affect fall safety in construction. The safety-related changes were comprised of fall-related hazards, including elevated platforms, unprotected edges, uncovered openings, ladders, and fall-arrest systems. To Illustrate the relevance to safety in construction in this experiment, Fig. 3 shows an original image and the manipulated image side by side for both safety-relevant and safety-irrelevant changes.

Worker's Intention

In this study, the authors implemented an intentional approach and the participants were instructed regarding the changes in the images and the types of changes they could expect to see. Therefore, participants devoted all available cognitive resources to detecting changes and to deciding whether the changes they recognized were related to safety.

Type of Task and Response

This study used detection and identification as the tasks for participants. Detection, the most widely used type of task, measures the responses of participants to the presence of a change in the display. The identification task requires the subject to respond to the identity of the change itself (i.e., the type of change). Thus, participants were expected to detect the changes they saw and decide whether the changes were related to safety or not by marking "yes/no" explicitly. The explicit "yes/no" response somewhat guaranteed that the participant identified and truly experienced the safety-relevant/irrelevant changes.

Data Collection

Participants

A total of 126 participants (29 experienced workers, 31 experienced students, and 66 novices) aged 18–62 years [Mean $(M) = 27.1$, $SD = 10.0$] were recruited to participate in a single 20-min change-detection experiment. The student sample consisted of 33 females and 64 males from the department of civil engineering at George Mason University. Student participants were aged 18–40 years ($M = 23.5$, $SD = 4.2$) and, on average, had a year of work experience ($SD = 2.5$ years). The experienced workers' sample consisted of 29 workers (5 female, 24 male) aged 19–62 years ($M = 39.3$, $SD = 14.0$) and, on average, had 14.1 years of work experience ($SD = 11.0$ years). One worker did not finish the experiment and was removed from the statistical analyses. Participants were recruited through on-campus fliers, posting an invitation flyer at construction sites, and stopping by construction companies' main offices. All participants provided written informed consent, and students received credit points and workers were given \$15 gift cards as compensation after the experiment. All procedures were approved by the Institutional Review Board (IRB) of George Mason University.

Change-Detection Task

As mentioned previously, this study implemented a gap-contingent (flicker) technique, and all 30 images were displayed in random order for each participant. With regard to the cycle and number of presentations of images, the research team followed the guidelines suggested by Vierck et al. (2008) to present the images in a constant repetitive cycle and for an equal number of presentations for the full duration of each trial. Each experiment took an average of 20 min to complete, and the cycle time for each image displayed was limited to 60 s or until a response was made.

The experiment was conducted on a 0.43-m (17-in.) laptop, and the images (previously characterized) were centered on the screen, which had a 1,024 × 768 display. Image pairs were presented using a flicker paradigm, in which two alternating images were presented in such a way that an original version and a modified version were displayed for 200 ms each, with 150 ms of blank screen in between; this intermittent display created a flickering appearance (Fig. 4). This cycle was repeated until the subject noticed the change or gave up on the search for a change between the images.

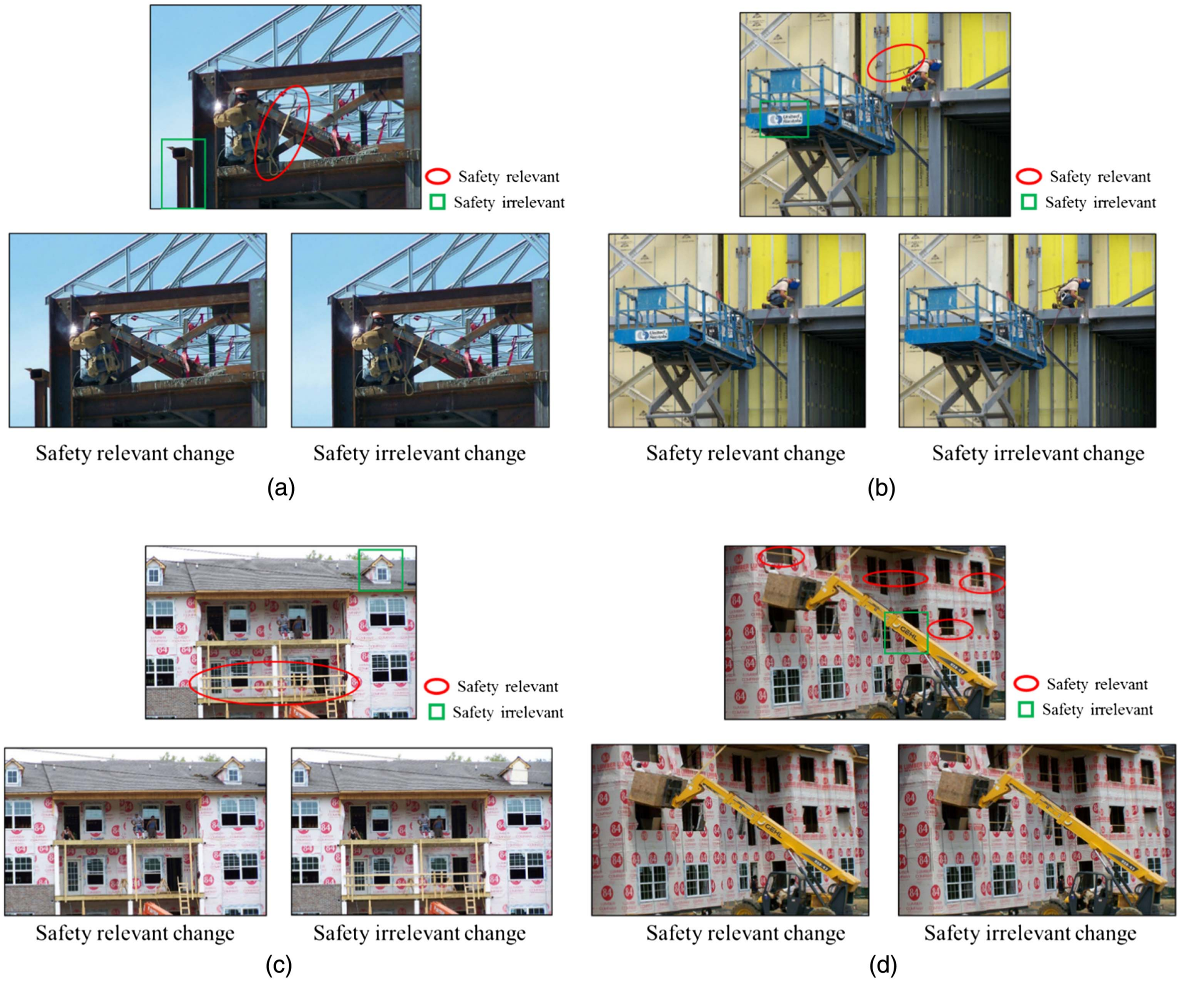


Fig. 3. Potential safety-relevant and safety-irrelevant changes in construction scenario images: (a) harness or tie off, safety-relevant change; steel column, safety-irrelevant change; (b) lanyard, safety-relevant change; logo on machinery, safety-irrelevant change; (c) guardrail, safety-relevant change; window, safety-irrelevant change; and (d) window rails, safety-relevant change; logo on machinery, safety-irrelevant change. (Images courtesy of David Ausmus.)

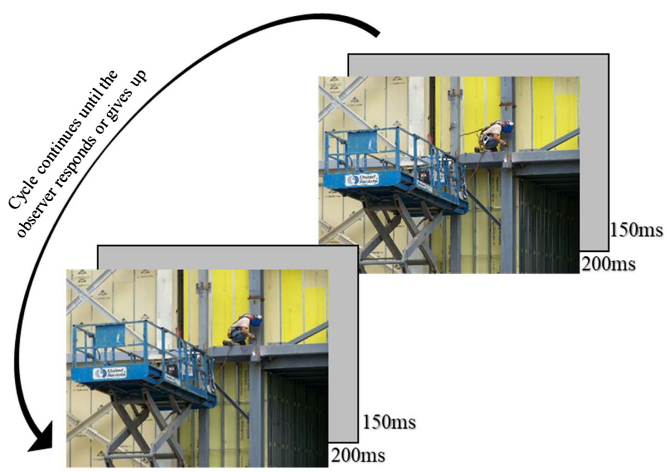


Fig. 4. The sequence of images is displayed as follows: the original image followed by the modified image, with a blank screen superimposed between the two images. In this example, the lanyard tying the worker in the original image disappears in the modified image. (Images courtesy of David Ausmus.)

Procedure

Participants completed the experiment individually and were seated approximately 50 cm away from the display screen. All participants had normal or corrected-to-normal vision. First, participants completed a brief demographic questionnaire; then, they were prompted to read the instructions, which explained how two nearly identical images would alternate back and forth, with a blank screen interrupting the images. Their task was to detect a change between the two images and press a button on the keyboard, after which they indicated whether the change was safety relevant or safety irrelevant. To ensure that participants understood the task and the response requirements, a short demonstration with example stimuli appeared on the display. Following this, they completed the change-detection and change-identification task and pressed the keyboard button according to the directions. This whole cycle was repeated for all 30 images.

Data Analysis Approach

The experimental setup included two types of changes (safety-relevant and safety irrelevant changes), three levels of work experience (experienced worker, experienced student, and novice), and

Table 2. Descriptive statistics for response times and accuracy

Groups	Types of change	Response time (ms)		Accuracy rate (%)	
		Mean	SD	Mean	SD
All groups	Safety relevant	10,551	3,810	72	18.1
	Safety irrelevant	14,233	5,940	61	20.5
Experienced workers	Safety relevant	12,052	4,307	75	19.4
	Safety irrelevant	16,650	8,402	60	23.2
Students with experience	Safety relevant	10,041	3,510	74	15.9
	Safety irrelevant	13,679	4,457	57	21.1
Students with no experience (novices)	Safety relevant	10,132	3,596	70	18.4
	Safety irrelevant	13,443	5,006	63	18.9

Table 3. Statistical results for differences in response time and accuracy rate for groups across two types of changes (safety-relevant and safety-irrelevant changes) (Hypothesis I)

Groups	Response time (ms)		Accuracy rate (%)	
	Test statistics	p-value	Test statistics	p-value
All groups	5.33	0.000^{***}	4.40	0.000^{***}
Experienced workers	2.36	0.018^{*}	2.76	0.006^{**}
Students with experience	3.23	0.002^{**}	3.12	0.002^{**}
Students with no experience (novices)	3.95	0.000^{***}	2.12	0.033^{*}

Note: $^{*}p < 0.05$; $^{**}p < 0.01$; and $^{***}p < 0.001$.

five types of fall hazards (elevated platforms; unprotected edges; uncovered openings; ladders; and fall-arrest systems). The change-detection performance of the subjects was assessed through two variables: (1) response time (RT)—the amount of time it took for each participant to detect a change relative to the onset of the trial, and (2) accuracy of participants in detecting the changes with respect to relevance to safety. Only response times for correct detections (i.e., responses in which the observer detected the change accurately) were calculated for each participant (see Table 2 for accuracy rate). Based on the distribution of the data, the most appropriate statistical analyses were chosen and conducted.

Results

The descriptive statistics for the mean response times and percent accuracy for each subject group for each of the different types of changes can be found in Table 2. Across all conditions, the mean response time for all participants was 10.55 s for safety-relevant changes and 14.23 s for safety-irrelevant changes. The mean accuracy rate for all participants was 72% for safety-relevant changes and 61% for safety-irrelevant changes. Thus, all three groups detected the safety-relevant changes more quickly and more accurately than the safety-irrelevant changes (see Table 3 for test statistics).

Among the groups, the student participants (including novices and those with work experience) usually demonstrated shorter response times in identifying the changes; however, although the experienced workers were slower in detecting changes, they were more accurate. The accuracy and response time of the descriptive analyses both indicated strong effects of types of change; further analyses were performed in order to elucidate these differences.

Hypothesis I: Types of Changes

The mean response times and accuracy rates for detecting changes were not normally distributed (Shapiro-Wilk test: $p = 0.007$ and $p < 0.001$, respectively). The results of the Mann-Whitney test indicated significant differences in mean response times ($Z = 5.33$, $p < 0.001$) and accuracy rates ($Z = 4.4$, $p < 0.001$) for all participants across the two types of changes (i.e., safety-relevant and safety-irrelevant changes). Significance tests, discussed in the following, were conducted in order to examine whether response time and accuracy rate varied according to types of changes for each participant group. Assumptions of normality and homogeneity of variance were tested in order to select the appropriate statistical analysis.

Regarding response times for subjects' detecting changes, the assumptions of normality (Shapiro-Wilk test: $p = 0.047$) and homogeneity of variance (Levene's test: $p = 0.002$) were violated for experienced workers (perhaps due to the large standard deviation of years of experience). Therefore, the nonparametric Mann-Whitney test was used to compare the difference between mean response times for the change types among experienced workers. For students with experience, the normality for both types of changes (Shapiro-Wilk test: $p = 0.218$) and homogeneity of variance assumptions (Bartlett's test: $p = 0.440$) were met, so the t-test parametric test was used to examine changes in response time across the change types. For students with no experience, the response time was not normally distributed for irrelevant changes (Shapiro-Wilk test: $p = 0.015$); the homogeneity of variance was violated (Levene's test: $p = 0.008$), so the nonparametric Mann-Whitney test was used to compare the difference between the mean response time of two changes among students with no work experience. Among the groups, the response times differed significantly between change types for experienced workers, with faster detection of safety-relevant changes relative to safety-irrelevant changes ($Z = 2.36$, $p = 0.018$ for experts; $t = 3.23$, $p = 0.002$ for students with experience; and $Z = 3.95$, $p < 0.001$ for students with no experience) (Table 3).

Regarding accuracy rate, the assumption of normality was violated for all three subject groups for both safety-relevant (Shapiro-Wilk test: $p = 0.006$, $p = 0.021$, $p = 0.013 < 0.05$) and safety-irrelevant changes (Shapiro-Wilk test: $p = 0.018$, $p = 0.002$, $p = 0.028 < 0.05$). Therefore, the nonparametric Mann-Whitney test was again used to compare the difference between accuracy rates for the change types among all groups. The accuracy rates differed significantly between change types, with superior accuracy for safety-relevant changes relative to safety-irrelevant changes ($Z = 2.76$, $p = 0.006$ for experienced workers; $Z = 3.12$, $p = 0.002$ for students with experience; and $Z = 2.12$, $p = 0.034$ for students with no experience). Therefore, the ability to detect various fall hazard changes at jobsites was significantly impacted by the type of change (Table 3).

Hypothesis II: Different Types of Fall Hazard

To further examine whether a significant difference existed in the change-detection performance of groups across different types of fall hazards, the response times and accuracy rates associated with each type of fall hazard were examined across groups. There were 15 safety-relevant changes that were divided into five types of fall hazards: unprotected edges (4 items), elevated platforms (4 items), fall-arrest systems (4 items), ladders (2 items), and openings (1 item). Fig. 5 depicts the distribution of response time and accuracy rate among the three levels of work experience and across the five types of fall hazards.

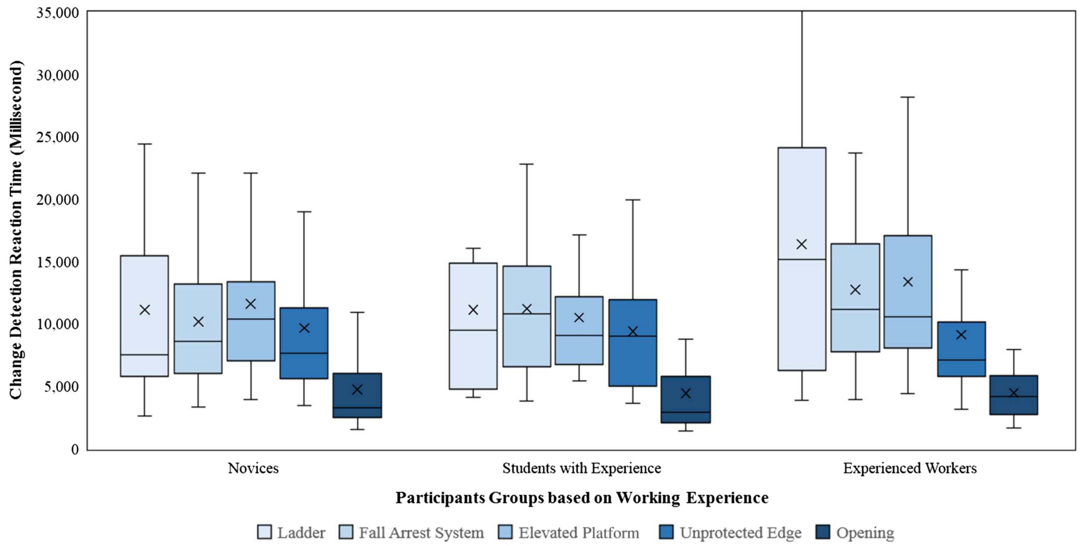


Fig. 5. Box plot of response times among groups for each hazard type. Analyses include only correct responses.

Table 4. Descriptive statistics grouped by fall hazards

Safety-relevant changes (fall hazards)	Groups	Response time (ms)		Accuracy rate (%)	
		Mean	SD	Mean	SD
Unprotected edges	All	8,894	8,158	68.1	30.4
	Experienced workers	8,750	8,153	69.0	28.8
	Students with experience	9,528	8,080	73.4	28.8
	Students with no experience	8,625	8,230	65.2	31.9
Elevated platforms	All	11,955	12,170	76.2	26.8
	Experienced workers	13,168	12,889	78.4	25.6
	Students with experience	10,933	10,569	80.6	22.1
	Students with no experience	11,912	12,598	73.1	29.2
Fall-arrest systems	All	10,966	11,006	82.7	19.1
	Experienced workers	12,313	12,333	80.2	20.5
	Students with experience	11,057	10,151	84.7	19.0
	Students with no experience	10,351	10,800	83.0	18.7
Ladders	All	12,768	12,852	51.6	40.9
	Experienced workers	16,611	16,736	65.5	38.0
	Students with experience	11,401	12,201	38.7	44.2
	Students with no experience	11,103	10,019	51.5	39.2
Openings	All	4,555	3,135	69.0	46.4
	Experienced workers	4,449	2,137	82.7	38.4
	Students with experience	4,411	3,842	77.4	42.5
	Students with no experience	4,708	3,241	59.1	49.5

The descriptive statistics for the mean accuracy rates and response times of workers and students, grouped by fall-hazard types, appear in Table 4. The opening fall hazard was removed from the comparison because there was only one item in the change detection experiment.

Before conducting any inferential statistical analysis, the research team tested assumptions such as normality (Shapiro-Wilk test: $p < 0.05$) and homogeneity of variance (Levene's test: $p < 0.001$). The results of the Kruskal-Wallis test showed that regardless of the level of work experience, there was a significant difference in response time for the different types of fall hazards among the participants ($\chi^2 = 27.78,\ p < 0.001$) (see Table 5). Posthoc

Table 5. Statistical results for differences in response time and accuracy rate for groups across different fall hazards (elevated platforms, unprotected edges, ladders, and fall-arrest systems) (Hypothesis II)

Groups	Response time (ms)		Accuracy rate (%)	
	Test statistics	p value	Test statistics	p value
All groups	27.78	0.000^{***}	181.58	0.000^{***}
Experienced workers	11.53	0.009^{**}	46.32	0.000^{***}
Students with experience	1.29	0.731	36.05	0.000^{***}
Students with no experience	19.47	0.000^{***}	98.12	0.000^{***}

Note: $^{*}p < 0.05$; $^{**}p < 0.01$; and $^{***}p < 0.001$.

analysis with Bonferroni adjustment indicated that among the different types of fall-hazard related changes, participants identified changes related to unprotected edges significantly faster than those related to elevated platforms and ladders ($p < 0.001$) and moderately faster than those related to fall-arrest systems ($p = 0.097 < 0.1$).

Regarding accuracy rate across different fall hazards, the results of the Kruskal-Wallis test indicated that regardless of the level of work experience, a significant difference in accuracy rates existed for workers' detecting the different types of fall hazards ($\chi^2 = 181.58$, $p < 0.001$) (Table 5). Posthoc analysis with Bonferroni adjustment showed that among the different types of fall-hazard related changes, participants identified changes related to unprotected edges, elevated platforms, and fall-arrest systems significantly more accurately than ladder hazards ($p < 0.001$). In addition, participants were also more accurate in detecting changes related to elevated platforms and fall-arrest systems than those related to unprotected edge hazards ($p < 0.001$ and $p = 0.004$, respectively). Therefore, the likelihood of detecting certain types of fall hazard changes at jobsites may depend on the types of fall risks.

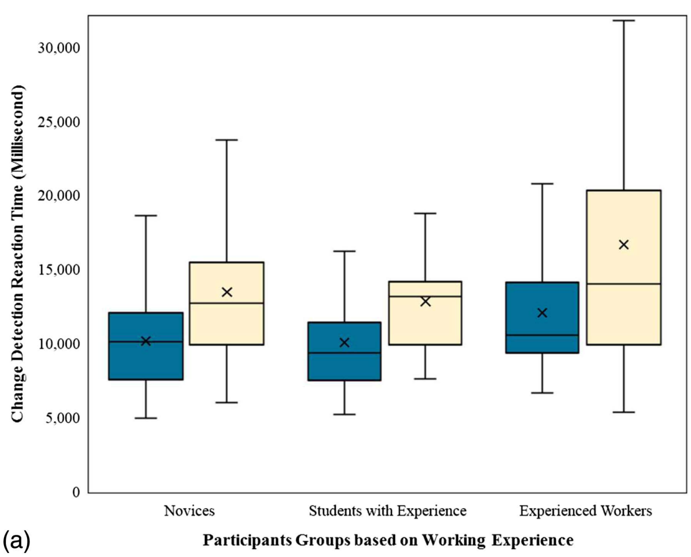
To further compare the mean response times associated with the different fall-hazard types for each group of participants, the Kruskal-Wallis test was used. The results of the Kruskal-Wallis test showed that the response times of workers ($\chi^2 = 11.53$, $p = 0.009$) and students with no experience ($\chi^2 = 19.47$, $p < 0.001$) in detecting changes were significantly different across different types of fall hazards (Table 5). However, there seemed to be no significant difference in the response time of students with experience for fall-hazard types ($\chi^2 = 1.29$, $p = 0.731$) (Table 5). Posthoc analysis with Bonferroni adjustment indicated that among different types of fall-hazard related changes, workers identified changes related to unprotected edges faster than those related to ladders and elevated platforms ($p = 0.009$ and $p = 0.037$, respectively). Furthermore, students with no experience also identified changes related to unprotected edges faster than those related to elevated platforms ($p < 0.001$). Changes in fall-arrest systems also were recognized moderately more quickly than those related to elevated platforms by students with no experience ($p = 0.090 < 0.1$).

For all levels of work experience, accuracy rates across the different types of fall hazards were not normally distributed (Shapiro-Wilk test: $p < 0.05$). The results of the Kruskal-Wallis test showed that the accuracy rate of workers ($\chi^2 = 46.32$, $p < 0.001$), students with experience ($\chi^2 = 36.05$, $p < 0.001$), and students with no experience ($\chi^2 = 98.12$, $p < 0.001$) were significantly different across different types of fall hazards (Table 5). Posthoc analysis with Bonferroni adjustment showed that all three groups were significantly different and identified the potential fall-related changes related to unprotected edges, elevated platforms, and fall arrest systems (significantly) more accurately than those related to ladders ($p < 0.001$). Workers were significantly more accurate in identifying fall-arrest system hazards than unprotected-edge hazards ($p = 0.018$). In addition, students with no experience were significantly less accurate in identifying unprotected-edge hazards compared to detecting fall-arrest system and elevated platform hazards ($p < 0.001$ and $p = 0.027$, respectively) and were more accurate in identifying fall-arrest system hazards than elevated platform hazards ($p = 0.030$).

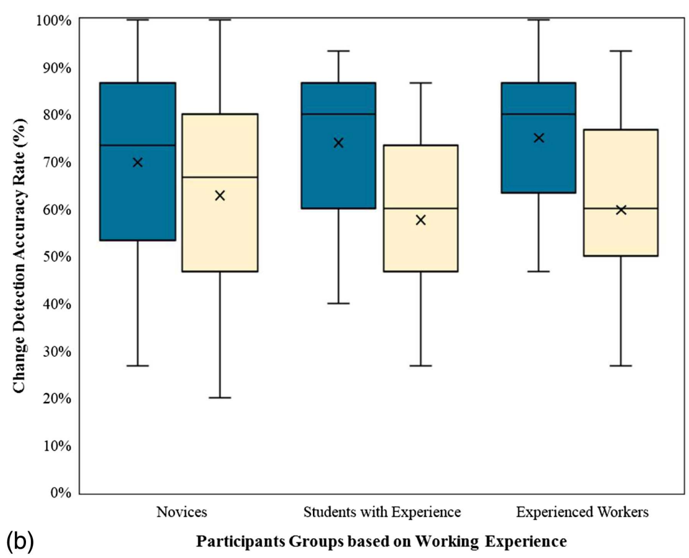
Hypothesis III: Role of Experience

The mean accuracy when detecting relevant changes for experienced workers was higher by 1% and 5% from students with experience and students with no experience, respectively (Table 2). While students with no experience detected safety-irrelevant changes more accurately than students with experience or experienced workers, the response time for students with experience was shorter in identifying safety-relevant changes in comparison to other groups; on average, the mean response time for students with experience for safety-relevant changes was 2.01 s faster than for experienced workers but was not different from that of students with no experience. Similarly, on average, the mean response time for students with experience for safetyirrelevant changes was 2.97 s faster than for experienced workers but only 0.24 s slower than that of students with no experience (Table 2). The differences among groups for safety-relevant and safety-irrelevant changes can be seen in Fig. 5; in order to test whether the work experience of the participants impacted their change-detection ability, the distributions for response time and accuracy rate for the three levels of experience were examined across two types of changes as seen in Fig. 6.

The response time for safety-relevant changes was normally distributed (Shapiro-Wilk test: $p > 0.05$). Therefore, a one-way



(a)



(b)

Fig. 6. Box plot of (a) response times; and (b) accuracy rate among experience groups for safety-relevant and safety-irrelevant changes.

Table 6. Statistical results for differences in response time and accuracy rates for groups across three levels of work experience (experienced worker; experienced student; and novice) (Hypothesis III)

Types of changes	Response time (ms)		Accuracy rate (%)	
	Test statistics	p value	Test statistics	p value
Safety relevant	3.16	0.047*	2.66	0.264
Safety irrelevant	2.73	0.255	1.01	0.602

Note: $^{*}p < 0.05$; $^{**}p < 0.01$; and $^{***}p < 0.001$.

ANOVA was used to determine if there was a significant difference between the groups for safety-relevant changes. The results indicated that response time differed significantly among the groups for safety-relevant changes [$F(2,120) = 3.16$, $p = 0.047 < 0.05$]. Posthoc comparisons using the Tukey-Kramer honestly significant difference (HSD) indicated that mean response time for experienced workers (M = 11,513, SD = 3,242) was slower than that of students with experience (M = 9,717, SD = 3,065, $p = 0.077 < 0.1$) and students without experience (M = 9,900, SD = 3,089, $p = 0.061 < 0.1$). However, change-detection response time did not differ significantly between students with experience and novices ($p = 0.962 > 0.05$). However, the response time for safety-irrelevant changes was not normally distributed (Shapiro-Wilk test: $p < 0.05$). Results from the Kruskal-Wallis test showed that response times for safety-irrelevant changes did not differ significantly among the groups with different levels of work experience ($\chi^2 = 2.73$, $p = 0.255 > 0.05$) (Table 6).

The accuracy rate for safety-relevant changes was not normally distributed (Shapiro-Wilk test: $p < 0.05$). Results from the Kruskal-Wallis test indicated that the accuracy rates for safety-relevant changes did not differ significantly among the groups with different levels of work experience ($\chi^2 = 2.66$, $p = 0.264 > 0.05$). The accuracy rate for safety-irrelevant changes was also not normally distributed (Shapiro-Wilk test: $p < 0.05$). Applying the same test, the accuracy rates for safety-irrelevant changes did not differ significantly among the groups with different levels of work experience ($\chi^2 = 1.01$, $p = 0.602 > 0.05$). Therefore, the ability to detect various changes (safety relevant) at jobsites was moderately impacted by the level of construction work experience with regard to response time, but there was less support for the role of experience to changes (both safety relevant/irrelevant) at jobsites with regard to accuracy rate.

Discussion

The findings of our study confirmed that change-detection performance varies across participants as a function of the change type, the subjects' work experience, and the changes' fall-hazard relevance.

Effect of Types of Safety Relevance on Change Blindness

These findings suggest that changes in safety relevance are associated with greater accuracy and shorter response times among all participants. The findings of this study show that individuals are better able to focus attention on and subsequently detect safety-relevant changes relative to safety-irrelevant changes. These findings are consistent with previous literature stating that changes made to objects in the center of interest of a scene are detected at a higher rate (Simons and Levin 1997). Note that center of interest does not necessarily imply the center of an image in spatial terms inasmuch as the most relevant items/areas in an image. Such a result indicates the importance of attention in change detection and highlights why individuals are more effective at identifying changes that have higher personal, task, or safety relevance (Rensink et al. 1997; Kevin O'Regan et al. 2000; Galpin et al. 2009). In contrast, safety-irrelevant changes were not identified as quickly or as accurately. This suggests that the relevance of a change is a critical predictor of whether a change will be noticed on a construction site. For example, if a logo on construction equipment disappeared in the experiment, it was not safety relevant, and observers took more time to detect such irrelevant changes. These significant differences with regard to response time for safety-relevant changes as compared to safety-irrelevant changes prove that the types of changes made affect the change-detection ability of workers.

Effect of Fall-Target Type on Change Blindness

Beyond the significant effect of change type, this study found significant effects of target type (i.e., potential causes of fall hazards) on participants' change-detection performance. Specifically, the change-detection performance of participants was low for potential fall hazards associated with ladders, with almost half of the participants proving slower to notice or inaccurate in detecting ladder-related changes (Table 4). However, changes relevant to unprotected edges, fall-arrest systems, and elevated platforms were recognized more accurately by all participants. One interpretation of this finding is that workers do not adequately attend to ladder-related fall hazards. This pattern suggests that participants, regardless of the level of work experience, perceived ladder-related hazards as less safety relevant, indicating the possibility that ladders may easily be overlooked relative to other items relevant to safety. This finding is important because it suggests that safety training sessions may be adjusted to better account for hazards that workers find less obvious. Therefore, future research should explore whether altering the design of safety training can ameliorate workers' change blindness for ladder-related fall hazards.

Interestingly, the findings indicated that generally, changes to unprotected edges were detected faster than other changes. One explanation is that the unprotected edges were larger objects in the scene, perhaps making the changes easier to detect. Another explanation could be the presence of a worker in the scene, who appeared close to the unprotected edge. There is a tendency for individuals to fixate on faces and people when presented with scenes, and a faster orientation to a worker may have facilitated change detection. Similar results have been reported in the driving literature, because there is evidence that drivers can detect certain types of hazards faster than others based on their perceived risk associated with the situation (Beanland et al. 2017; Crundall et al. 2012). Previous studies also have shown that as scene complexity increases, individuals' change-detection performance decreases significantly (e.g., Beck et al. 2007). Therefore, in complex and dynamic construction sites, change-detection performance will likely decrease for hazards workers perceive as less risky.

In summary, the differences in response time and accuracy rates when detecting hazard types clearly show that certain types of fall hazards are detected far more easily than others. This finding can help researchers and practitioners when investigating which hazard types are not easily detected (which could be mitigated with additional safety training) and can also provide workers with better hazard-identification training, because failure to detect hazards can potentially lead to inappropriate decisions and unsafe behaviors (Hasanzadeh et al. 2017a, b).

Effect of Work Experience on Change Blindness

Although there was no statistically significant difference in accuracy rate with regard to work experience, the results indicated that once the safety-relevant changes were detected, workers performed better in analyzing the nature of the changes correctly. Similarly, experienced students were more accurate in distinguishing safety-relevant changes from safety-irrelevant changes than students with no experience. A possible explanation for this finding may stem from the safety training received by participants. For example, in this study, workers had a greater proportion of safety training (83.33%), followed by experienced students, who had more safety training certifications (19.3%) than students with no experience (1.5%). In addition, the fact that students with no experience detected irrelevant changes better means that attention was likely distributed more broadly to detect all types of changes, whereas the other groups probably had a better sense of where to direct their attention given their experience or knowledge of common hazards on a construction site.

One of the unexpected findings was that experienced workers were actually slower to detect safety-relevant changes relative to the other two groups. One possible explanation for this is that experienced workers took more time to survey the scene carefully given the relevance of the task to their profession. Students may not have had the relevant experience or engagement with the task, which could have sped their responses.

Limitations and Future Studies

There are a few limitations that need to be noted for future change-detection experiments in the construction industry. This study was the first attempt to study change blindness empirically in construction-safety settings, so the change-detection experiment was conducted in a controlled laboratory environment. Real-world construction environments are dynamic, but it is difficult to reproduce this dynamic nature using static scenes. To further validate our findings, future studies should replicate the current research in real-world settings or in virtual-reality settings in order to account for the dynamic nature of a construction environment and to compare the differences in the ability of workers to detect changes in static and dynamic scenes. Moreover, only fall hazards were considered in this study; subsequent studies could incorporate other hazard types that are pertinent to construction safety. Although there are certainly other hazard types that are relevant to study, our main interest in the present study was the speed and accuracy in detecting safety-relevant changes relative to safety-irrelevant changes.

Future studies could incorporate change-detection experiments in training or other behavioral interventions in order to get a sense of whether there are specific hazard types for which workers need additional training in (e.g., hazards that they were slower to detect or were less accurate in identifying) so as to improve the situation awareness of workers. This has been a successful approach with driver perception because change blindness manipulations have been applied in experiences in order to make drivers more aware of the types of hazards they may commonly miss or detect (Gunnell et al. 2019). Researchers could also investigate the neural correlates of attention as they relate to change blindness by monitoring physiological responses or examining performance in a neuroimaging environment. Last, future studies could examine the effects of additional variables like personality, mindfulness, injury exposure, age of participant, and complacency on the degree of change blindness exhibited among workers in the construction industry.

Conclusion

Change blindness demonstrates that people fail to notice changes in their surrounding environment unless they are directly attending a relevant location at the time of the change. Given the importance of efficient processing of visual information for jobsite safety, it was critical to determine how attentional allocation was impacted by change relevance, change type, and worker experience, all of which influence performance. Regardless of work experience, subjects were faster and more accurate in locating changes relevant to safety than changes irrelevant to safety; subjects also performed significantly faster when responding to safety-relevant changes versus safety-irrelevant changes. Most notably, the results demonstrated that unprotected edge hazards were noticed faster and detected with higher accuracy than other fall-hazard types, suggesting that hazard type is an important variable to consider in safety training. Furthermore, among all types of fall hazards, the high degree of change blindness to ladder-related hazards was concerning and highlights the need to improve workers' hazard perception through motivational interventions and training and to ensure that workers attend appropriately to all potential causes of fall hazards on jobsites. These results have implications for future research, because they better inform us regarding the manner in which workers allocate visual attention within their environment. While the influence of work experience was not exactly as anticipated, experience clearly plays a role in terms of how the task is approached and carried out. Taken together, these results suggest that work experience helps facilitate slightly more efficient processing in safety-change-prone dynamic jobsites.

Data Availability Statement

All data, models, or code generated or used during the study are available from the corresponding author by request.

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