Construction workers’ awareness of safety information depending on physical and mental load

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ABSTRACT
Construction is one of the most dangerous occupations. The most prominent reason for worker accidents is unsafe behavior, particularly rooted in the inability to recognize and appropriately respond to risk factors. Previous studies have investigated worker perception and comprehension of construction hazards and safety information in laboratory settings. A relationship has been found between workload and workers’ situation awareness (SA), a useful concept for understanding risk perception and comprehension. However, it is necessary to investigate the actual construction environment to increase the real-world applicability of the research results. This experimental study analyzed workers’ SA in relation to physical and mental workloads acquired while performing work at a construction site. Perception (Level-1-SA) and comprehension (Level-2-SA) were measured using the SA Global Assessment Technique as subjects walked inside a facility under construction and performed inspection or construction works. Statistically significant differences were found between perception and comprehension of safety-related information. It was also found that mental load negatively affected SA. This study provided external validation of previously investigated effects of workload on workers’ perception and comprehension of safety-related elements at real construction sites. The study’s findings can improve the understanding of workers’ safety behaviors and help suggest directions for safety management guidelines.

1. Introduction
In spite of constant efforts to promote safety, the construction industry remains one of the most dangerous occupations and exhibits a high proportion of work-related injuries and deaths (Abbas, Mneymneh, and Khoury 2018). The causes of accidents in the construction industry include unsafe working methods, improper work plans, the human element, inadequate job site conditions, unsafe equipment, and poor management (Hamid, Majid, and Singh 2008). It is widely recognized that the most significant cause of accidents at construction sites is workers’ unsafe behavior (Dester and Blockley 1995; Heinrich, Petersen, and Roos 1980; McSween 2003). The main cause of unsafe behavior is the inadequate perception of and response...
to hazards and safety information at the construction site (Rundmo 1996; Smith and Hashtrudi-Zaad 2006; Tixier et al. 2014). Because workers’ cognitive abilities are affected by their physical and mental state (such as emotional instability or work-related fatigue) as well as the demanding environmental conditions onsite, workers’ perception and comprehension of sources of risk and safety information change in relation to these elements as well (Lee et al. 2012; Nazir, Colombo, and Manca 2012). Further, construction workers are subject to significant physical and mental workload as they perform their work, which alters their risk perception and comprehension (Loewenstein et al. 2001).

Much work has been done on the perception and comprehension of sources of risk and safety information that affect construction workers’ safety onsite (Abbas, Mneyneh, and Khoury 2018; Fang et al. 2015; Hasanzadeh, Esmaeili, and Dodd 2017a, 2017b; Perlman, Sacks, and Barak 2014). Perception of risk sources implies the ability to detect danger at the construction site. Comprehension of risk indicates the ability to understand the details of such risks (Horswill and McKenna 2004). Risk perception and comprehension can be understood as part of situation awareness (SA) of potential danger in the work environment. The SA concept is widely used in ergonomics. Endsley (1995a) originally defined SA as “the perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their future status.” That is, SA is the ability to continuously acquire information from the environment, use the experience to predict outcomes, and act effectively in response (Artman 2000). Utilization of SA, risk perception, and comprehension ability while performing demanding work tasks has been examined in experiments in simulated environments (Choi, Ahn, and Seo 2020; Fang et al. 2015; Hasanzadeh, Esmaeili, and Dodd 2017a). To increase the applicability of the outcomes of this type of research to real work sites, it is necessary to examine worker behavior at those sites. This study analyzed perception and comprehension of safety-related situations and information in construction workers in relation to their physical and mental conditions in a real-world experiment. To compensate for the limitations of previous work performed in a laboratory setting, this experiment was conducted at an actual construction site, and the analyses were performed to take into account the range of physical and mental workload that appears in real work tasks.

2. Literature review

2.1. Construction workers safety behavior

About 88% of all industrial accidents are caused by unsafe human behavior (Shin, Gwak, and Lee 2015). In the construction industry, in particular, it is essential to manage unsafe behavior due to the higher accident and mortality rates than in other industries (Abbas, Mneyneh, and Khoury 2018). The greater risk may be due to the fact that construction workers have relatively low hazard perception and risk comprehension capabilities due to the diverse and dynamic attributes of their work (Albert, Hallowell, and Kleiner 2014). An understanding of the factors that affect hazard perception and risk comprehension is necessary if safety performance in the construction industry is to be improved (Pandit et al. 2019).

Workers’ hazard perception and risk comprehension differ by individual, depending on a range of factors (Choudhry and Fang 2008). Among these are work experience (Hasanzadeh, Esmaeili, and Dodd 2017b; Sneddon, Mearns, and Flin 2006) and job position (Chen et al. 2012; Hallowell 2010). It has also been reported that task familiarity may reduce workers’ hazard perception (Zimolong and Elke 2006). Researchers have also examined the relationship between physical and mental load and hazard and safety perception. For example, Chen, Song, and Lin (2016) collected electroencephalogram data from construction workers to determine the relationship between mental load and risk perception, finding that increasing mental load decreases perception ability, and the higher the workload, the greater the error and accident rate. According to Sneddon, Mearns, and Flin (2006), excessive workload makes workers less able to perceive their situation, in a state called “cognitive tunnel vision” (Tversky and Kahneman 1974). Because construction workers may be exposed to poor working conditions and work-related hazards, they are likely to experience physical and mental fatigue (Jebelli et al. 2018). Thus, they may have reduced perception in task performance that entails high physical and mental load, which may lead to safety accidents. Safety management practices that enhance hazard perception and risk comprehension in construction workers are needed during construction tasks.

2.2. Situation awareness

Construction workers’ hazard perception and risk comprehension can be better understood through the

![Figure 1. Conceptual diagram of situation awareness (Endsley 1995a).](image-url)
improvement of their SA. The concept of SA first appeared in the field of ergonomics, but it has received a broad application in a variety of domains, including in the construction industry. SA refers to the individual’s understanding of “what is going on” (Endsley 1995b), and several models (the three-level, activity theory, distributed cognition, and perceptual cycle models, among others) provide the theoretical basis for SA (Gregoriades and Sutcliffe 2018). The most widely accepted model among these is Endsley’s (1995b) three-level model, which describes SA on three levels: level 1, the perception of elements in the current situation; level 2, the comprehension of the current situation; and level 3, the projection of future status (Figure 1). Level 1 is the most fundamental component of SA. If SA is to be achieved, the working environment must be continuously monitored to detect changes in stimuli (Sneddon, Mearns, and Flin 2006). However, attention is selective, as workers cannot pay attention to every detail of their working environment, and important elements can thus be missed or ignored at level 1 (Simons 2000). In level 2, the importance of a situation is understood through the combination, interpretation, storage, and preservation of information (Endsley and Garland 2000). The level of comprehension achieved varies from person to person, and having a poor or incorrect mental model can increase accident risk (Sneddon, Mearns, and Flin 2006). Level 3 is a projection that combines level 1 and level 2, incorporating the prediction of possible future conditions and events (Endsley 1995b). The ability to accurately predict possible futures enables an appropriate course of action to achieve the goal (Stanton, Chambers, and Piggott 2001). The most common methods for measuring an individual’s SA level include the Situation Awareness Rating Technique (SART) and the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, Sollenberger, and Stein 2000). In SART, participants use a Likert scale to assess their cognitive abilities. Although this method simplifies the measurement process, the results are subjective and depend on the participants’ abilities (Hasanzadeh, Esmaeili, and Dodd 2016). By contrast, SAGAT, developed by Endsley (1995a), is one of the most widely used questionnaire methods for measuring SA. SAGAT measures SA by asking participants questions about specific information that could represent their SA at each moment during a simulation or an experiment and scores the participants’ responses (Endsley 1995a). During the experiment, tasks are randomly paused (i.e., SA freeze), and subjects are asked questions for each SA level. These queries are not posed during task execution (Endsley 1995a). After the questions and responses, the activity is resumed, and this process is repeated to produce a quantitative measure of SA.

Maintaining good SA is essential for successful hazard perception and risk comprehension among construction workers because hazard perception and risk comprehension share the concepts of levels 1 and 2 SA, respectively (Fang and Cho 2017; Perlman, Sacks, and Barak 2014). Poor SA can expose workers to dangers (Hasanzadeh, Esmaeili, and Dodd 2016). Several studies have examined the relationship between workers and SA in safety management. For example, Sneddon, Mearns, and Flin (2013) analyzed the factors affecting workers’ SA by surveying drilling workers by using a five-point-scale-based questionnaire. They found that high levels of stress, sleep problems, and fatigue were associated with low levels of SA among offshore drilling workers, and low SA was associated with increased unsafe behaviors. The worksite stressors that affected worker attention and SA were studied, including vibration, noise, pollution, temperature, and light levels (Endsley 1995b), all of which are inevitably poorly managed at construction sites, thereby causing worker stress and impairing safety behaviors (Leung, Chan, and Yu 2012).

In addition, experimental studies in simulated laboratory settings have been conducted. Hasanzadeh, Esmaeili, and Dodd (2016) measured construction workers’ SA by using a mobile eye-tracker as the workers watched a screen displaying construction images to identify hazards in images and compared the results with survey-based subjective SA ratings to find associations between them. By using a simulated virtual-reality experimental environment, Choi, Ahn, and Seo (2020) demonstrated that the SA of forklift operators might decrease when they perform cognitively demanding loading or unloading tasks. Twenty subjects operated a forklift to perform tasks in virtual environments, and their SA was measured using the SAGAT method. Fang et al. (2015) conducted an experiment involving 20 workers in an indoor laboratory to study the effects of physical demand on workers and found that physical demand reduces workers’ attention and increases their error rate, which negatively affect safety performance. To prevent accidents in the construction industry, it is necessary to confirm the results of previous studies on workers’ hazard perception and risk comprehension in terms of SA through further field studies, including how and to what extent SA changes during onsite construction work.

3. Knowledge gap and hypotheses

Various factors, such as physical or mental load, work experience, and familiarity with the site, have been found to affect workers’ SA. In the construction industry in particular, physical and mental load is an unavoidable factor, and effective safety management requires a proper understanding of the impact of workload on workers’ SA. Thus far, the effects of physical and mental loads on SA have largely been experimentally examined in controlled laboratory settings (Choi,
Ahn, and Seo 2020; Fang et al. 2015; Hasanzadeh, Esmaeili, and Dodd 2016). Applying the outcomes of such studies to complex and real construction sites is necessary to conduct experiments in actual working environments.

The objective of this study is to compare and analyze workers’ SA under different conditions of physical and mental load at the actual construction site and investigate the effect of workload on the ability to perceive and comprehend safety-related information. In this study, it was hypothesized that the greater the physical and mental load, the lower the SA of the construction workers in a real-world experiment. Interaction between physical and mental load was also hypothesized.

4. Research processes

4.1. Experimental setup and subject

In all, 30 healthy subjects were recruited for the experiment, all of whom were adults over 19 years old. Among these subjects, one was <20 years old, 16 were 20–29 years old, six were 30–39 years old, one was 40–49 years old, and six were 50–59 years old. Of the subjects, 13 were real construction workers and 17 were to be future occupants of the building after construction and were inspecting the building. None of them reported any physical and emotional problems or cognitive disorders. A prior power analysis based on obtaining the desired power of .80, with two factors (i.e., physical load and mental load) in a two-way repeated-measures analysis-of-variance (ANOVA), with an alpha of .05 and a medium effect size of .25, yielded a reasonable sample size of 24. The experimental protocol was approved by the researchers’ university’s institutional review board, and the experiment was conducted from September 10 to 25, 2019. The experiment was conducted at the construction site for the Ewha Womans University Research Cooperation Building, where interior work and subsidiary work were in progress. The experiment was conducted in four sessions, with the sessions classified according to a combination of high and low physical load conditions and high and low mental load conditions during the performance of real construction and inspection work tasks (Table 1).

To measure SA, the authors used SAGAT. SA queries are determined using goal-directed task analysis, which seeks to relate to how humans perceive and process information about a situation (Endsley 2000). In this study, the subjects’ goal was to safely perform construction work or inspect the building’s interior work quality at a real construction site. In this regard, safety signs and firefighting equipment informing construction site’s risks and safety-related information were deemed essential objects to facilitate the subjects’ awareness and understanding of the relevant situation to ensure safe working. Therefore, the safety signs used at the construction site and firefighting equipment were selected as target SA objects to examine the subjects’ perception and comprehension of the situation. The queries that were most relevant to each level of SA were composed from the target SA objects (Table 2). Level 1 SA is the perception of the SA objects. The subjects were asked to indicate whether they saw the safety signs or equipment. Level 2 SA refers to workers’ comprehension of the meaning and information on the safety signs or equipment. The subjects reported locations, colors, and shapes of the signs or equipment. The response options for the location of the sign were right and left. There were four response options (blue, green, red, or yellow) for the color of the sign or the equipment and four options (circle, square, rhombus, or triangle) for the shape. If the subject perceived but did not comprehend the sign, the remark “unknown” was added to the response.

To quantify the SA response scale, one point was given if the subject’s response matched the actual experimental environment, and zero points were given if it did not. The maximum score for level 1 was five points per session, with five SA target objects assigned to each session. The maximum score for level 2 was ten points per session, with two questions answered per SA target object. The summed scores for each level were standardized to give a score value between zero and one.

More than 15 safety signs and firefighting equipment were placed for each session, and the subjects were asked to stop at a point (i.e., SA freeze) during the experiment and then asked questions regarding five randomly selected SA objects. Figure 2 shows a plan view of the locations of the safety signs and equipment and the SA freeze point in each session, as well as a detailed timeline.

### Table 1. Sessions according to load conditions.

| Physical Load | Mental Load | Session |
|---------------|-------------|---------|
| High (HM)     | High (HP)   | Session 1 (HP-HM) |
| Low (LM)      | Low (LP)   | Session 2 (LP-HM) |
| (word recall) | (break)     | Session 3 (LP-LM) |
|               |             | Session 4 (LP-LM) |

### Table 2. SAGAT questions.

| Level of SA (Comprehension) | SAGAT Questions (yes or no) |
|-----------------------------|-----------------------------|
| Level 1 (Perception)        | Did you see the safety sign (or equipment)? |
| Level 2 (Comprehension)     | Where was the safety sign (or equipment) located? |
|                             | What did the safety sign (or equipment) look like? |
|                             | What color was the safety sign (or equipment)? |
|                             | (circle, square, rhombus, or unknown) |
|                             | (blue, green, red, or unknown) |

### Figure 2. Plan view of the locations of the safety signs and equipment and the SA freeze point in each session.
of the session. Because the sessions were repeated four times, a learning effect could be anticipated. To minimize this effect, the order of the sessions was randomized for each subject. Each session had about a 5-minute duration, with a 5-minute break between sessions. The entire experiment was photographed and recorded with a camera (Go-pro Hero 7 Black). The subject’s physiological and movement signals (including heart rate and
three-axis acceleration data that capture movement signals) were collected using a wearable wrist sensor (Empatica E4, Empatica, Inc., MA, USA) to indicate whether appropriate levels of workload had been assigned. Figure 3 presents examples of the equipment used in the experiment and the experiment process.

4.2. Induction of physical and mental loads

Physical and mental loads were induced for the participants. Previous studies that investigated the effects of physical load on individuals also exerted a simulated physical load. For example, Azevedo et al. (2014) and Zhang, Kaber, and Hsiang (2010) used a treadmill to apply a constant physical load to their subjects. However, an artificial load does not reflect the real world. This study applied a similar level of physical load to that applied to a construction worker during work. This load was induced during an authentic inspection. For high physical load, the subjects went up and downstairs during the break before the session. For sessions with low physical load, the subjects sat down and rested during the break interval.

Using physical and physiological data, it is possible to objectively determine the impact of physical load on the subject (Jebelli et al. 2018). In this study, heart rate data and three-axis acceleration data collected from a wearable wristband sensor (Empatica E4) were used to measure subjects’ physical movements.

Mental load was induced using the word recall test. This is a memory test in which subjects are presented with words and asked to remember as many of them as possible in the short term (Goldstein 2014). Memory tasks require attention, and the use of memory and attention constitutes mental load (Epling, Russell, and Helton 2016). Study subjects were asked to memorize 10 work-related words before the session and then write the words that they remembered after the session. Inspection- or construction-related words were randomly assigned to each subject.

5. Results

5.1. SA and physical and mental loads

SA score data were analyzed to investigate how well the subjects perceived and comprehended their situation under conditions of physical and mental load. The average SA scores were compared for each session, and a paired t-test was performed to determine whether a significant difference in SA scores appeared between levels 1 and 2. Then, a two-way repeated-measures ANOVA was performed to determine whether there was a statistically significant difference in subjects’ SA scores under different conditions of physical and mental load. A post hoc test was then performed to test the difference in average SA scores between the load conditions.

Table 3 and Figure 4 present the descriptive statistics for SA scores per SA level and session. In session 4, low physical load and low mental load (LP-LM), subjects had the highest score at both level 1 (M = 0.707, SD = 0.202) and level 2 (M = 0.477, SD = 0.174). In other words, the subjects perceived and comprehended the surrounding situation most correctly when no workload was applied. On the other hand, subjects received the lowest score in session 2 (LP-HM) (M = 0.580,
Table 4. Results of post hoc test by load.

| Level 1 SA | Mean Difference | Std. Error | df  | t   | $P_{tukey}$ |
|-----------|----------------|------------|-----|-----|-------------|
| Mental Load High | Low | −0.063* | 0.0354 | 29.0 | −1.79 | 0.084 |
| Physical Load High | Low | 0.00333 | 0.0341 | 29.0 | 0.0978 | 0.923 |

| Level 2 SA | Mean Difference | Std. Error | df  | t   | $P_{tukey}$ |
|-----------|----------------|------------|-----|-----|-------------|
| Mental Load High | Low | −0.0583** | 0.0285 | 29.0 | −2.05 | 0.050 |
| Physical Load High | Low | −0.0217 | 0.0306 | 29.0 | −0.709 | 0.484 |

* Significant at the 0.1 level  
** Significant at the 0.05 level

SD = 0.231 for Level 1 SA, and M = 0.363, SD = 0.201 for Level 2 SA). This result shows that the subjects had difficulty concentrating on their surroundings when under mental load.

The paired t-test indicates a statistically significant difference between levels 1 and 2 for sessions 1 (t = 7.39, p < 0.001), 2 (t = 7.74, p < 0.001), 3 (t = 7.87, p < 0.001), and 4 (t = 6.46, p < 0.001). The rate of change in SA scores between levels 1 and 2 (i.e., the fall in level 2 score compared to level 1 score) was the largest in session 1 (HP-HM session: −38.64%) and the lowest in session 4 (LP-LM session: −32.53%). Thus, level 2 SA was significantly lower than level 1 SA under both physical and mental workload conditions. That is, even if subjects clearly perceived the target object, they could less easily comprehend its meaning in session 1 than in session 4 when they were not given a significant workload.

A two-way repeated-measures ANOVA showed that the SA score changed statistically significantly according to mental load at levels 1 and 2 SA. For mental load, the reduction on level 1 SA was significant at the 0.1 level (F(1,29) = 3.203, p = 0.084), and the effect on level 2 SA was significant at the 0.05 level (F(1,29) = 4.197, p = 0.05). However, the physical load did not significantly affect the SA score, and there was no interaction between physical and mental load. The results of the post hoc test (Table 4) showed a statistically significant mean difference according to mental load at level 1 SA (MD = −0.063, p = 0.084) and level 2 SA (MD = −0.058, p = 0.050).

5.2. SA and subject’s physiological and movement signals

Because the degree of physical demand on a subject when performing physical-load tasks varies across individuals, the authors additionally measured the subjects’ heart rates by using a wearable wristband sensor (Empatica E4) and converted the measured

![Figure 5. Physical and physiological data collected through E4 and their transformation.](image-url)
values to percentage of heart rate reserve (%HRR), which is a relative HR measurement that is useful for measuring physical demands (Hwang and Lee 2017), to evaluate the effect of physical workload (Figure 5) while considering individual differences. The %HRR is calculated by normalizing the original absolute HR by using the individual’s minimum and maximum beat-per-minute HR data (ACSM 2013). The subjects’ average values were 34.54%HRR in session 1 (HP-HM), 31.30%HRR in session 2 (LP-HM), 29.47%HRR in session 3 (HP-LM), and 28.83%HRR in session 4 (LP-LM). However, there was no significant relationship between %HRR and SA scores ($r = -0.06$, $p = 0.51$ for %HRR and level 1 SA score; $r = -0.07$, $p = 0.44$ for %HRR and level 2 SA score).

Furthermore, this study analyzed the relationship between subjects’ walking speed and SA. The authors collected three-axis acceleration data by using a wearable wristband sensor and used the average peak distance from the acceleration data to assess walking speeds (Figure 5). Level 1 SA showed a negative correlation with the average peak distance $X$ at the 0.1 level ($r = -0.16$, $p = 0.09$). Word recall was negatively correlated with average peak distance $X$ at the 0.05 level ($r = -0.29$, $p = 0.03$) and average peak distance $Y$ at the 0.1 level ($r = -0.25$, $p = 0.06$).

6. Discussion

In the complex environment of a construction site, a worker’s physical and mental state changes continuously according to the load appearing in their tasks. This study investigated the effects of physical and mental load on the worker’s SA. The results of this study can improve the understanding of worker conditions that influence SA in construction workers.

First, the worker’s comprehension level (level 2 SA) regarding the surrounding environment is always statistically significantly lower than the perception level (level 1 SA). This indicates that workers who see objects around them may have difficulty understanding them. The subjects’ SA significantly decreased when they were given a mental workload. In stressful work conditions, such as mental workload, it is difficult to efficiently gather information, and workers are more likely to succumb to attention tunneling (Endsley 2016), or a narrowing of attention during concentration.

Unlike mental load, physical load did not statistically significantly affect subjects’ SA. In previous studies, subjects were given an artificially high physical load during the experiment. However, in this study, the subjects were given a load that was similar to a usual physical load at a construction site. As explained before, the subjects’ %HRR between sessions ranged from 28% to 35%. Previously, Hwang and Lee (2017) measured 17 construction workers’ %HRR over a day and found that workers’ %HRRs was less than 38%, which is consistent with the measurement results obtained in this study. The results indicate that this actual physical load was insufficient to affect the subjects’ SA. In this regard, %HRR values between 20% and 40% are considered a light aerobic activity that does not cause noticeable changes in breathing rate and can be sustained for at least 60 min (Norton, Norton, and Sadgrove 2010). Therefore, the demand on workers due to a typical physical load at the construction site (e.g., walking, going up and down the stairs) did not appear to have much impact on their SA. Additionally, people tend to slow their movements when they experience excessive physical load. Thus, when individuals feel physical demand while working, they will likely offset the negative impact of the physical demand on their SA by slowing their walking speed. Furthermore, the faster the subjects walked with higher average peak distances as represented in the subject’s acceleration signals, the more difficult they found it to perceive the surrounding situation due to their lower attention.

These findings suggest a direction for safety management in construction workers. First, it is necessary to increase ease of comprehensibility in safety signs or safety-related equipment more understandable to enable workers to correctly understand information on the objects that they see due to the significant difference between perception and comprehension. Next, the worker’s SA tends to significantly decrease under mental load. Therefore, more careful supervision is required when construction workers are working on construction tasks with excessive mental load, especially when workers must keep their own work in mind or are not familiar with their tasks or the site. Workers should also be regularly trained in hazard perception and risk comprehension in various situations, including mental and physical load. Supervision can improve worker safety by altering critical behavior among workers (Choudhry 2014). It was also found that workers’ self-controlling mechanisms of dealing with workloads, such as slowing walking speed, effectively alleviate the effects of workload on risk perception and comprehension. Management and training must prevent unnecessary fast walking or excessively rapid pace of work.

This study provides added value due to its close relation to real conditions at a construction site, not in a laboratory environment. Physical loads that are typical at construction sites, such as going upstairs or walking quickly, did not significantly affect workers’ SA. In future studies, similar experiments can be conducted to allow subjects to perform tasks with higher physical loads. Further, the use of physiological signals (e.g., electrodermal monitoring of arousal) will produce an improved understanding of the relationship between physical and mental load and worker SA by
providing a more accurate means of capturing human responses from physical and mental workloads (Jebelli, Choi, and Lee 2019).

7. Conclusions
This study investigated the relationship between levels 1 and 2 SA and the physical and mental loads of construction workers in a real-world experiment. Four experimental sessions were created with different conditions of physical and mental load to measure subjects’ SA. Regardless of the physical and mental load, the level 2 SA (comprehension) score was statistically significantly lower than the level 1 SA (perception) score. The results also indicated that subjects’ SA in their surrounding situation is significantly affected by the mental workload. The findings in this study can improve the understanding of construction workers’ SA and provide direction for safety management guidelines.

Most previous studies have been limited by being conducted in a laboratory, not on a job site. This study, by contrast, was conducted at a real construction site. This study is meaningful in that it provides external validation of the effect of workload on workers’ perception and comprehension of safety-related elements at actual construction sites. It is also significant in that it empirically accounts for unsafe worker behavior and an unsafe construction environment. The results of this study may find application in future studies to investigate and theorize the relationship between human factors, SA, and safety performance at real construction sites.

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