Psychological Antecedents of Risk-Taking Behavior in Construction

Antoine J.-P. Tixier, S.M.ASCE[1]; Matthew R. Hallowell, A.M.ASCE[2]; Alex Albert, A.M.ASCE[3]; Leaf van Boven[4]; and Brian M. Kleiner[5]

Abstract: Despite strong advancements in construction safety performance over the past few decades, injuries still occur at an unacceptable rate. Researchers have shown that risk-taking behavior, originating mainly from inaccurate perception and unacceptable tolerance of safety risk, is a significant factor in a majority of construction injuries. Based on psychology research that suggests cognitive interactions between emotions and risk perception, the hypothesis was formed that there are objectively measureable differences in construction safety risk perception between people in different emotional states. To test this hypothesis, a controlled experiment was designed and conducted that (1) induced various positive and negative emotions in 69 subjects using validated movie excerpts; (2) measured emotional states using a validated post-film questionnaire; (3) exposed participants to construction hazards within a high fidelity virtual environment; and (4) measured subjects' perceptions of the risk related to these hazards adopting a validated frequency-severity-based questionnaire. Once these data were collected, a principal component analysis (PCA) was performed to identify uncorrelated groups of related emotions. A Kruskal-Wallis test followed by multiple Mann-Whitney U tests was then used to test for differences in risk perception between participants belonging to these different emotional groups. The results of these analyses indicated that the mild negative group (sad and unhappy subjects) and the intense negative group (fearful, anxious, and disgusted subjects) perceived statistically significantly ($p = 0.003$) more risk than the positive group (happy, amused, joyful, and interested subjects). The two negative groups were also found to perceive more risk than the neutral group ($p < 0.02$). However, no statistically significant difference in risk perception was found between the positive and neutral groups or between the two negative groups. According to situational awareness literature, the implication of these findings is that individuals in positive and neutral emotional states may be more prone to engage in risk-taking behaviors than their counterparts because they perceive less risk in the same environment. **DOI: 10.1061/(ASCE)CO.1943-7862.0000894.**

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Introduction

Construction remains one of the most dangerous industries in the United States despite the improvements that followed the inception of the Occupational Safety and Health Act of 1970. In fact, construction employs 7% of the national workforce but accounts for 17% of all work-related deaths (Bureau of Labor Statistics 2011). It is estimated that there are over 1,000 fatalities and 230,000 injuries each year that result in over $15 billion in direct costs (Bureau of Labor Statistics 2011). Agarwal and Everett (1997) have estimated that worker compensation premiums alone account for 1.5–6.9% of total costs of new construction, a figure that appears to remain stable (Waehrer et al. 2007).

Injuries occur even when comprehensive safety programs are in place in part because workers take risks (Howell et al. 2002). In fact, Hinze (2006) showed that over 75% of construction injuries were caused by unsafe worker actions, which are ultimately the result of poor training, lack of hazard recognition skills, inadequate safety systems, and risky behavior. Carter and Smith (2006) explain that risk-taking behavior originates mainly from workers' inability to adequately perceive and respond to risk, and is not deliberate. Thus, understanding the psychological factors that influence risk perception is essential to long-term safety improvement.

Presently, no studies have examined the role that emotions play in hazard recognition, risk perception, or risk-taking behavior in construction environments. This aims to address this knowledge gap by measuring the relationship between positive and negative emotions and risk perception in a risk-free, but realistic and complex, virtual construction environment. Such new knowledge contributes to a better understanding of the psychological aspects of human unsafe behavior, and tests the translation of traditional psychological theories into an occupational-like context. The impetus for this research was curiosity resulting from a review of applied and cognitive psychology literature.

Background and Points of Departure

To understand how this study builds upon and departs from current knowledge, relevant literature has been reviewed in the areas of

[1]Ph.D. Student, Dept. of Civil, Environmental, and Architectural Engineering, Univ. of Colorado at Boulder, 1111 Engineering Dr., Boulder, CO 80309-0428. E-mail: antoine.tixier-1@colorado.edu

[2]Assistant Professor and Beavers Faculty Fellow, Dept. of Civil, Environmental, and Architectural Engineering, Univ. of Colorado at Boulder, 1111 Engineering Dr., Boulder, CO 80309-0428 (corresponding author). E-mail: matthew.hallowell@colorado.edu

[3]Postdoctoral Researcher, Dept. of Civil, Environmental, and Architectural Engineering, Univ. of Colorado at Boulder, 1111 Engineering Dr., Boulder, CO 80309-0428. E-mail: alex.albert@colorado.edu

[4]Associate Professor, Dept. of Psychology and Neuroscience, Univ. of Colorado at Boulder, 1111 Engineering Dr., Boulder, CO 80309-0428. E-mail: leaf.vanboven@colorado.edu

[5]Director, Myers-Lawson School of Construction; and Professor of Industrial and Systems Engineering, Virginia Tech, 1425 S Main St., Blacksburg, VA 24061. E-mail: bkleiner@vt.edu

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situational awareness and the interplay between emotions, risk perception, and risk-taking. Because the construction domain is devoid of rigorous empirical investigations into the psychology of risk-taking behavior in construction environments, this literature review includes findings from many industries and nonoccupational contexts.

Situational Awareness and the Role of Risk Perception in Decision-Making under Uncertainty

In human factors engineering, situational awareness is defined as a motivated, active, and continuous extraction of information from an environment and the ability to use experience to anticipate consequences of actions and act effectively (Artman 2000). As shown in Fig. 1, situational awareness is a three-step process that includes detection of hazardous signals, perception, and comprehension of the risks associated with the hazards, and projection of the consequences associated with decision options (Endsley 1995). In construction, risk perception (Level II) is critical because, even if hazards are identified (Level I), workers may involuntarily behave unsafely when they inaccurately perceive and value risk (Zimolong 1985).

Psychologists hypothesize that emotions greatly influence signal detection, risk perception, and the process of risk-based decision-making as a whole. Unfortunately, researchers have yet to reach consensus regarding the exact nature of these emotional interferences. Furthermore, there is a dearth of studies that validate theory in real-life contexts. The results of the experiment will contribute to this ongoing debate and test the extent to which the main theories in the field translate to real-life oriented environments.

Interplay between Emotions and Risk-Taking

Emotions are mental, internal, affective states that refer to how a person feels and what the feeling is about. Emotions have been shown to impact risk-based decision-making by directly acting on cognitive processes of decision-making and by indirectly influencing risk perception (Clore et al. 1994). The relationship between emotions and risk-taking is also thought to be bidirectional because engaging in risky activities can give birth to strong emotional experiences (Bonnet et al. 2008).

Researchers have provided physiological evidence that emotions affect cognition and risk-taking decisions. For example, using positron emission tomography (PET), Drevets and Raichle (1998) observed that brain blood fluxes decreased in the areas mainly dedicated to risk-based decision-making when intense emotional states were induced. PET is a radiological procedure used in nuclear medicine to produce three-dimensional images and trace metabolic activity in the human body. Bechara et al. (1997) found corroborating evidence that individuals with brain damage in the prefrontal cortex, the area of the brain that controls decision-making, were unable to develop the necessary emotional anticipatory reactions that subconsciously guide risk-taking behavior. Interestingly, this assertion is also supported by Patrick (1994), who demonstrated that an explanation for the engagement of psychopaths in abnormal risk-taking behaviors lay in their

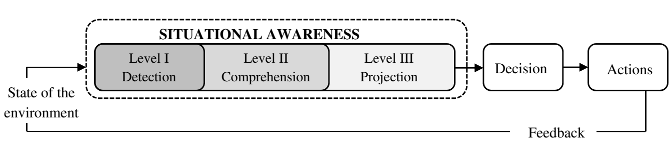

Fig. 1. Conceptual model of situational awareness

inability to fully experience anticipatory negative emotions such as fear and anxiety when contemplating the outcomes of risky choices.

Many theoreticians have made claims about the role of emotions in risk-perception and risk-based decision-making. For example, Finucane et al. (2000) proposed that an affect heuristic may influence general risk perception when a potential event (e.g., injury) is described in terms of a tragic outcome. In such a situation, Keller et al. (2006) suggest that people use their emotions as a way to estimate the probability of occurrence of an adverse event, and that evoking a negative affect associated with the event may result in a greater perceived risk. Loewenstein et al.'s (2001) prominent *risk-as-feelings* hypothesis posits that specific emotions, such as worry, fear, dread, and anxiety, guide human responses to dangerous situations. Likewise, Johnson and Tversky's (1983) *affective generalization* hypothesis proposes that emotions influence decision-making because they inform individuals about the current state of their environment. The subconscious impact of emotional messages on judgment is thought to be even more significant in situations where a risk-based decision must to be made under high pressure and time constraints (LeDoux 1996), as is very common in construction.

Even though theoreticians broadly agree that there is a strong relationship between emotions and risk-taking, studies have produced equivocal results regarding the nature of this relationship. Some of the salient findings from psychology literature are as follows:

- Participants with positive emotional states were more risk averse than neutral people when potential losses were large (Nygren et al. 1996),
- Participants with positive emotional states were prone to take higher risks than neutral people when potential losses were low (Isen and Patrick 1983),
- Participants who were depressed were more risk averse than participants with neutral or positive emotional states (Yuen and Lee 2003), and
- Participants who were anxious were more risk averse than their low-anxiety counterparts (Eisenberg et al. 1996).

It is clear that emotions play a significant role in risk-based decision-making, especially with respect to risk perception. However, it is also clear that the nature of the relationship between emotions and risk-taking is not completely understood. In addition, because of the numerous challenges associated with inducing, measuring, and observing the effect of emotions, most of the aforementioned research was conducted through artificial contexts such as gambling tasks or scenarios, where experimenters had much more control and ability to observe the phenomenon at play. Consequently, there is a need for studies where settings are closer to real-life and where consequences of actions can be related to real outcomes, such as this experiment.

Research Objectives and Sampling Strategy

To test the hypothesis that there is an association between emotional states and perceived risk in construction environments, a controlled experiment was designed and executed using a virtual construction site. The data collection objectives were to (1) induce various positive and negative emotions using validated and effective video clips, (2) objectively measure emotional states with a validated post-film questionnaire, and (3) objectively measure risk perception using a validated scale and operational definitions of potential outcomes. Once these data were collected, multivariate

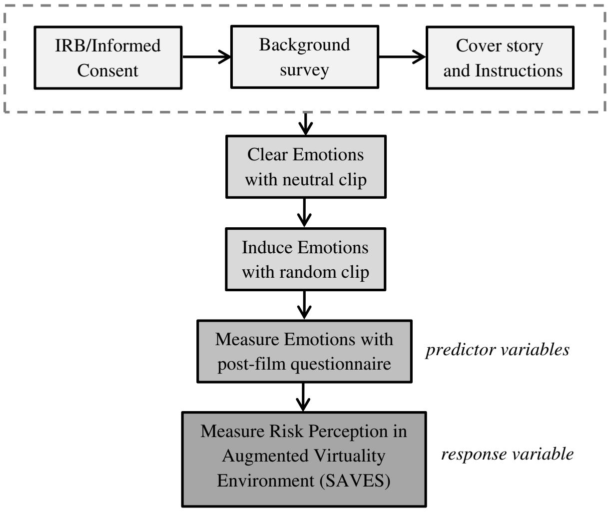

Fig. 2. Overarching data collection approach

statistical methods were used to reduce the dimensions of the dataset and measure relationships between emotions and risk perception. Here, details of the data collection process are reviewed, with particular emphasis on the subject recruitment, experimental design, and the valid and reliable measurement of the independent variables (emotions) and the dependent variable (risk perception). The overarching research approach is illustrated in Fig. 2.

The sample consisted of 69 participants, 58 University of Colorado at Boulder Civil, Environmental, Architectural and Engineering undergraduates and 11 graduate students. Consistent with the department demographics, 77% were male and the mean age was 23 years with a standard deviation of 4.64 years (minimum = 20, maximum = 52). A total of 31 students (45%) had participated in at least one significant professional construction site experience, such as a summer internship (laborer or management position). All participants had already taken part in at least two site tours during their curriculum. Subjects were recruited via class announcements, and participation was voluntary. Participants were not compensated for their involvement in the study.

When selecting participants, a dilemma arose. Ideally, both students and workers would be included as subjects. Although the use of workers as subjects to test the hypothesis would have ultimately extended the inferences, using students allowed testing of the hypothesis independently of the biases that exist with workers' recent experiences. Because resources and access to workers were limited, students were used as the subjects.

This constraint is ultimately an asset because students theoretically respond more genuinely and candidly to construction risks, being less likely than workers to be biased by their past experiences when presented with specific construction situations. For example, a veteran welder may not see a situation where a torch is very close to an acetylene tank as hazardous, because they may have behaved in such a fashion for years without having experienced any negative outcome. However, someone with a basic understanding of the construction domain, and with existent but not extensive construction site experience, may rightfully perceive more risk to be associated with the situation. The absence of these experiential biases among the study participants allowed measuring of the impact of the induced emotions on risk perception with an improved signal-to-noise ratio. Thus, the strength of this study is the rigor of the experimental design and validity of the hypothesis testing.

Experimental Design

The experiment was conducted in four different sessions that took place over the course of three days. Each session was 90 min in length and was held in a computer lab that had been reserved for the occasion. Working with small groups limited unwanted interaction between subjects and allowed research coordinators to communicate instructions efficiently and ensure that every participant was following directions carefully.

When conducting psychological experiments, it is essential to have a properly controlled laboratory in order to guarantee high levels of internal validity. This is especially true when investigating emotions because they can be influenced by various parameters such as comfort level, interaction with other participants, and other distractions. Consequently, great care was taken to set up an ideal laboratory environment following recommendations from past literature. Each participant was sitting on a comfortable chair, in front of a powerful computer (8 GB of RAM, 3.2 GHz) featuring a 27 in. $1{,}920 \times 1{,}080$ pixel monitor. The room was well-ventilated, temperature-controlled, and moderately lit. There were no other activities being conducted in the proximate space. Each subject had their own set of headphones and the ability to adjust volume to their comfort. There were 4 participants on each row of the lab, which allowed a distance of about 3.5 ft on each side between them. The computer towers served as separations between the monitors so that it was impossible for a participant to see their neighbors' monitors. Caution was taken with the appearance and behavior of the coordinators during the experiment. The role of each coordinator was previously determined and practiced so that each coordinator behaved consistently with the other and conveyed a sense of confidence while providing instructions. Their clothing was ordinary to avoid subconscious influences on participants' behaviors (Bargh and Ferguson 2000). Also, each participant was treated in the same neutral manner to limit any undesired emotional interference.

Introductory Activities and Experimental Set-Up

It was important that the subjects were unaware of the project objectives to avoid awareness biases. Accordingly, they were provided with plausible explanations for the purpose of their activities and tasks, thereby creating a simple but convincing cover story that followed Harmon-Jones et al.'s (2007) guidelines and which complied with the Institutional Review Board. It was explained that the sole purpose of the study was to increase subjects' hazard recognition skills using a virtual environment and to test the effectiveness of this environment as a training tool. To explain the emotional inducement, it was claimed that an unrelated mini-experiment was being conducted first in order to help a colleague from the psychology department, which involved viewing two brief video clips and completing a questionnaire. The participants were not debriefed about the true purpose of the experiment until all groups were done with the laboratory sessions. The subterfuge of the side study is a very common way to elaborate a cover story in social science experiments (Wilson et al. 2010). Once the cover story was provided, and before the viewing of the videos, a background survey was also administered that requested basic demographic information from each participant such as age, gender, construction experience, and others.

Inducing Emotions with Movie Clips

Numerous techniques have been used by researchers to induce emotions. Some examples include essay writing on emotional memories (Schaefer and Philippot 2005), mental role-playing tasks

Table 1. Selected Emotions and Movie Clips Used to Elicit Specific Emotions

Arget emotion	Movie clip	Duration	Origin
Neutral (baseline)	Denali National Park	3:40	Rottenberg et al. (2007)
Neutral (control)	Gabon: The Last Eden	3:06	Rottenberg et al. (2007)
Anger	Schindler's List	2:39	Schaefer et al.'s (2010)
Sadness	The Champ	3:21	Hewig et al. (2005)
Fear	The Silence of the Lambs	4:17	Rottenberg et al. (2007)
Happiness	Whose Line Is it Anyway?	2:13	Rottenberg et al. (2007)

(Schaefer et al. 2003), emotional statement reading (Velten 1968), imaginal mood treatment (Boyle 1984), facial and respiratory feedback (Philippot et al. 2002), unexpected gifts (Isen and Patrick 1983), exposure to images and music (Lynn et al. 2012), or movie excerpt viewing (Rottenberg et al. 2007).

Movie clips were selected because this technique combines many of the strengths of the other methods, and literature provided very strong support. In fact, exposure to movie extracts has become a standard emotion-eliciting technique, used in numerous fields such as social and cognitive psychology, neuroscience, medical imaging, marketing, and persuasion (Verduyn et al. 2013. Karama et al. (2011) provided clinical support for the selection by demonstrating, using magnetic resonance imagery (MRI), that emotional film clip viewing led to strong specific brain area activation. Using video clips also minimizes practical and ethical challenges because it is time efficient, has a high degree of ecological validity, and allows a great deal of standardization that promotes internal validity and cross-comparison with other studies (Gross and Levenson 1995). Movie extracts are also less likely to be perceived by participants as deceptive or manipulative, compared with other emotion induction techniques (Ross et al. 1975), and subject's attentional capture is usually very high (Rottenberg et al. 2007). Finally, it should be noted that the fair use of short copyrighted movie extracts for teaching or research purpose is not an infringement of copyright, as outlined under Title 17, Section 107 of U.S. Copyright Law. The movie clips shown in Table 1 were used in this study to elicit the specific emotions noted.

Selection of Specific Movie Clips

An extensive body of literature has proposed, tested, and validated movie excerpt batteries for eliciting various emotional states (e.g., Schaefer et al. 2010; Rottenberg et al. 2007; Von Leupoldt et al. 2007). Because movies are deeply anchored in the norms and the culture of their time, only film clips belonging to the most recent and updated validated databases available were picked. However, even these recent studies offer quite old movies mainly from the 1990s and 1980s. These clips were selected from because it was crucial to only use material that had been previously validated by the literature in order to further increase the internal validity of the experiment.

The aim was to elicit what are traditionally viewed in psychology as the basic (or discrete) emotions: anger, fear, sadness, and happiness (Clore et al. 1994). Therefore, four movie clips (one for each emotion) were selected. Following Rottenberg et al.'s (2007) advice, one neutral clip was used to neutralize the emotional states of all participants when starting the experiment. A second neutral clip was used to create a control group from a randomly selected sample of subjects. Movie clips were created from the full-length movies, in high definition (1,080 × 720 pixels, 30 frames per second) and audio quality (126 kbps, 44 kHz, stereo). It should be noted that the primary goal for using these clips was to create variability in participants' emotional states in order to obtain well-defined positive and negative groups. It was not the aim to test the effectiveness of the clips in eliciting their target emotions.

Residence Time of Induced Emotions

To increase even more the internal validity of the experiment, the fact that emotions change and evolve rapidly over time was taken into account (Verduyn et al. 2011; Rottenberg et al. 2007).

Indeed, it has been demonstrated that a typical residence time, the period between the onset point and the moment the emotion is no longer experienced, can be only a few seconds up to a couple of hours or days (Gilboa and Revelle 1994; Fitness and Fletcher 1993). Recent researchers have collected more precise empirical data that considerably enhanced the understanding of the duration of emotional episodes (Table 2). As one can see, residence time for various emotions ranges from 11 to 26 min, with a median over 15 min. Therefore, to make sure the emotional inducement was still effective, the decision was made to measure risk perception only within the first 15 min following the end of the emotion-inducing clip, which is considered to be a conservative choice (Fig. 3). As will be discussed, the greater part of the participants was done with risk perception measurement tasks well before this 15 min period was complete. To enhance the rigor of the study, caution was used to only select and use the highest ranked and most intense clips available in the literature, as the more intense the elicited emotion is in the first place, the longer the residence time (Verduyn et al. 2009; Schimmack 2003; Sonnemans and Frijda 1995).

As indicated, all participants started the experiment by watching a neutral clip. Following this clip, participants were randomly assigned an emotion eliciting-clip, or, for the randomly selected control group, a second neutral clip. Participants' emotional states were measured after the second movie-clip using Rottenberg et al.'s (2007) post-film questionnaire. This questionnaire asks participants to rate the amount of their emotional experience for 18 various different basic and complex emotion terms (e.g., anger, joy, fear, anxiety, pride) using 9-point Likert scales (a rating of zero corresponding to "not at all," a rating of 9 to "a great deal"). This revealed the type of emotions subjects experienced as well as the intensity of their emotional experiences themselves. For brevity,

Table 2. Residence Time for Specific Emotions

Emotion	Residence time (min)	Number of participants	Study
Fear	16	110	Verduyn et al. 2009
Anger	22	110	
	11	50	
	12	344	Verduyn et al. 2011
Joy	26	110	Verduyn et al. 2009
	19	50	
	12	344	Verduyn et al. 2011
Sadness	20	50	Verduyn et al. 2009
	15	344	Verduyn et al. 2011

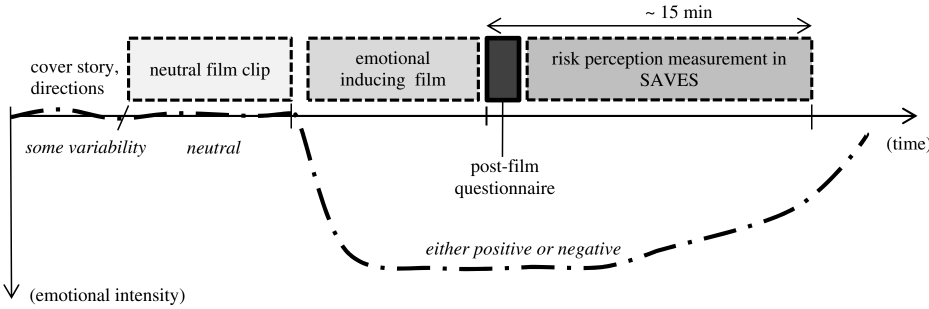

Fig. 3. Duration of emotional episode through the experiment

the Rottenberg et al.'s (2007) questionnaire cannot be provided here; however, it is available in the referenced paper.

Augmented Virtual Construction Environment

The experiment had access to a high fidelity virtual environment of an industrial construction site that was developed in past research (Hallowell et al. 2013). Just like a video game, this system, known as augmented virtual construction environment (SAVES), immerses participants into a highly realistic virtual worksite that was created based on a real building information model and over 200 photographs of real representative worksites. The SAVES system has an integrated questionnaire that is used to quantify risk perception as a subject navigates the virtual environment and encounters embedded hazards. Confidence in using this tool existed because Slater (2009) showed that people can behave realistically when responding to immersive virtual environments such as SAVES.

With the exception of measuring risk perception on an actual construction site, it is believed that immersion into SAVES was the best method available for simulating actual construction risks in a highly realistic fashion. It was impractical and potentially unsafe to manipulate participants' emotions and measure their risk perception on-site. Alternatively, SAVES allows subjects to experience situations that are unsafe without being exposed to actual risk. Additionally, the laboratory environment was preferred over a construction site because it allowed an optimal control, was a more stable environment over time, and, therefore, reduced the nonmeasurable interferences that could modify participants' emotions.

As opposed to augmented *reality*, which adds computer-generated information to a real environment, SAVES can be qualified of being an augmented *virtuality* tool, in that it incorporates real-world pictures into a virtual environment. As users encounter a hazard in SAVES, a high definition still picture representing the hazard within a real construction situation emerges. The situations vary in dangerousness, ranging from benign to extremely hazardous. Participants come across the different hazards randomly as they move about the virtual construction site. Hazards are of various types, originating from different energy sources, such as for instance electricity (e.g., transformers), pressure (compressed gas cylinders), radiation (welding arcs), or gravity (suspended loads).

Measuring Risk Perception

Risk perception can be defined as the judgment that one makes about the frequency and severity of specific risks (Slovic et al. 1980). Typically, these values are obtained by questioning individuals about different risk scenarios and aggregating the data. To measure risk objectively and to allow comparison among participants, an objective method of quantifying risk designed by Baradan and Usmen (2006) was used. In this approach, safety risk is defined as the product of the frequency (incident per worker-hours) and relative severity level (S) should the injury occur. The relationship between safety risk, frequency, and severity is shown by Eq. (1)

$$\text{Safety Risk}(S/w-h) = \text{Frequency}\ (\text{incidents}/w-h) \times \text{Severity}\ (S/\text{incident}) \qquad (1)$$

As indicated in Fig. 4, each participant was asked to quantify the frequency with which each severity level would be realized in the depicted environment. This approach has been used and validated in past research (Hallowell 2010). When providing frequency and severity estimates, participants were asked to respond based solely

Picture #: __________

From the best of your knowledge and your experience of construction sites (if it applies), <u>in this situation</u>, what will be the frequency of each of the following outcomes? Answer according to what is actually going to happen in reality, NOT according to what you think or feel. Please check where it applies.

Injury type	Once every week	Once every month	Once every year	Once every ten years
First aid				
Medical case				
Lost work time				
Permanent disablement or fatality				

Fig. 4. Risk perception data collection instrument

on what they thought would really happen in the exact same situation depicted by the picture. Subjects were asked to fill out a risk perception table for the first five hazards they encountered. After 15 min, the answers were collected even if the five tables were not completed because, as was already discussed, the emotional inducement could no longer be assumed to be effective. For almost all students, 15 min was more than enough to encounter five hazards and fill five questionnaires. Whether students' estimations of frequencies were truly accurate or not, did not matter because the only interest was to *compare* between subjects in different emotional states. Also, in everyday life, people act upon their perceptions of risks rather than the true risk faced, which is unknown.

To ensure consistency, participants were given injury severity definitions based on the Occupational Safety and Health Administration (OSHA) definitions, which they could access at any time during the experiment via provided handouts:

- First aid: Any treatment of minor scratches, cuts, burns, splinters, and so on, where the worker is able to return to work following the treatment;
- Medical case: Any work-related injury or illness requiring medical care or treatment beyond first aid where the worker is able to return to their regular work and function in normal capacity;
- Lost work time: Any work-related injury or illness that prevents the worker from returning to work the following day; and
- Permanent disablement or fatality: Any work-related injury or illness that results in permanent disablement or death.

The subjects were informed that the assumption was that one worker-week was equivalent to 40 worker-hours, which gave 167 worker-hours per month, and 2,000 worker-hours per year. When computing the risk perception scores, the product of these frequency levels and the associated severity scores quantified by Hallowell and Gambatese (2008) were used. The relative severity scores included: first aid ($S = 45$), lost work-time (128), medical case (256), and permanent disablement and fatality (13,619). For more information on these relative severity scores, reference Hallowell and Gambatese (2008).

When computing a participant's aggregated risk perception score, the risk perceived was summed at each severity level. Table 3 shows the risk perception values that correspond to the data collection instrument in Fig. 4, the frequency values, and severity scores discussed. As an example, if a participant believed, for a particular depicted condition, that a first aid injury would occur once a week, a medical case or lost work-time injury would occur once a month, and a permanent disablement or fatality would occur once a year, the participant's risk perception score would be calculated as $1.13 + 0.77 + 1.54 + 6.81 = 10.25$. In total, each participant completed five risk perception tables, which yielded five risk perception scores per subject.

Data Analysis

The data analysis involved reducing the five risk perception scores to one overall risk perception score per participant, reducing the dimensions of the dataset to principal emotions using PCA, and measuring differences in risk perception scores among groups of subjects sharing the same emotional states. This process is illustrated in Fig. 5.

Clustering Emotions Using Principal Component Analysis

To model the relationship between subjects' emotions and their risk perception, the dimension of the data set was reduced using principal component analysis (PCA). PCA is a well-known dimension reduction method that allows the user to identify small subspaces of a data set that contain most of the dynamics of the observed system (Joliffe 1986). Specifically, PCA was used to identify highly correlated emotions and group them together as new uncorrelated independent variables, thus making the interpretation of the relationship between emotions and risk perception more efficient. One of the advantages of PCA is that, while dramatically reducing the dimensionality of the original data set, it retains most of the information initially present (Massey 1965).

Although PCA is primarily intended for continuous data, Muthén and Kaplan (1985) showed that PCA performs quite well with ordered categorical variables such as answers to Likert scales, especially for data reduction and clustering. More precisely, Muthén (2004) found that it is possible to find true parameter values in PCA with Likert scale data. In this study, PCA was only used as a way to identify clusters among the independent related variables.

As noted by Comrey and Lee (1992) and Tabachnick and Fidell (2001), a minimum of 10 observations per independent variable is an absolute minimum to use PCA. Thus, 7 emotions were removed from the initial set of 18 emotions: anger (9 observations), love (4), pride (4), shame (4), contempt (1), guilt (0), and embarrassment (0). The remaining emotions were: interest (49 observations), happiness (26), amusement (25), sadness (23), anxiety (21), joy (20), unhappiness (19), fear (18), surprise (15), disgust (13), and confusion (12). According to Hatcher (1994), to obtain strong PCA groupings, the number of subjects should be greater than five times the number of variables being analyzed. With the 11 independent variables, and a number of subjects of 69 people, this requirement was exceeded ($69 > 55$).

SPSS 21.0 was used to perform the PCA. As recommended by Tabachnick and Fidell (2007), an oblique rotation method was used to start. The direct-oblimin technique was used, the most commonly used of the oblique rotation methods (Kim and Mueller 1978). Three iterations of the PCA were needed before obtaining significant results. Following the recommendations of Norman and Streiner (2007), two variables, confusion and surprise, were removed because they had individual sampling adequacy scores below 0.7. The determinant of the final correlation matrix was 0.01, indicating the absence of multicollinearity issues (Field et al. 2012).

The Kaiser-Meyer-Oklin (KMO) test of global sampling adequacy ($0.801 > 0.7$) suggested that it was appropriate to use

Table 3. Unit Risks Showed for Each Combination of Severity and Frequency of the Risk Perception Table

Severity	Once a week $1/(40\text{w-h})$	Once a month $1/(166.7\text{w-h})$	Once a year $1/(2,000\text{w-h})$	Once every 10 years $1/(20,000\text{w-h})$
First aid injury (45.255)	1.13	0.27	2.26×10^{-2}	2.26×10^{-3}
Medical case (128)	3.20	0.77	6.40×10^{-2}	6.40×10^{-3}
Loss work time (256)	6.40	1.54	1.28×10^{-1}	1.28×10^{-2}
Permanent disablement or fatality (13.619)	340.5	81.7	6.81	6.81×10^{-1}

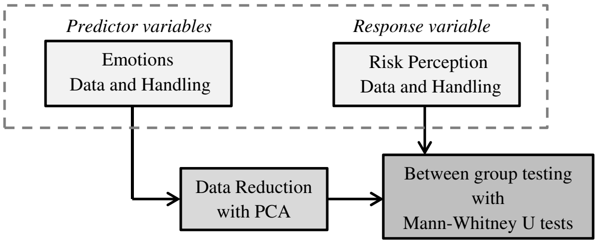

Fig. 5. Emotions data and handling

PCA, and the Bartlett's test of sphericity ($p < 0.001$) showed that the variables under study were related, a necessary observation for dimension reduction with PCA.

The final three-component model accounted for approximately 73% of the variance present in the initial data set. The output in SPSS for an oblique rotation method includes both a pattern and a structure matrix. Because PCA was only used to cluster emotions into groups, there is interest only in the pattern matrix (shown in Table 4) because it represents the loadings of the components on each variable, or, in other words, the groupings. According to Kline (2002) and Bryant and Yarnold (1995), in a simple structure, each component should have a few loadings close to zero. Furthermore, loadings of 0.3 or higher can be considered significant (Kline 2002). It can be seen from the pattern matrix that under these definitions, a perfect simple structure is almost reached. Only two of the variables (anxiety and sadness) could be qualified as somewhat complex. In addition, the model makes sense from a theoretical standpoint, as the variables loading on component 1 (joy, happiness, and amusement) all measure a positive state. Similar conclusions for component 2 (fear, anxiety, disgust) and component 3 (sadness and unhappiness) were drawn. These findings are not only statistically significant but also supported by theories in past literature (Cisler et al. 2009; Boyle 1984).

Accepting the Three-Component Model

Communalities account for the percent of variance in the independent variables explained by all the components at the same time, and may be considered as a measure of the reliability of the model (Garson 2008). According to MacCallum et al. (2001), communalities greater than 0.6 are considered significant, regardless of sample size. All of the communalities were above this threshold except for interest (0.504), and most were very high (0.849 for happiness, 0.829 for joy, 0.827 for sadness, and 0.783 for unhappiness), suggesting a very strong and accurate three-component model.

Risk Perception Data Handling

Each participant completed a risk perception table for each of the first five pictures encountered in the first 15 min following the randomly assigned movie clip. For each of the five photographs encountered, a participant's risk perception score was standardized as shown in Eq. (2). A single risk perception score was computed for each participant by averaging their five normalized risk perception scores. Because subjects were free to move about the virtual environment and encountered pictures randomly, some pictures were encountered by less than three participants. Risk perception scores were not computed for these pictures

$$\mathrm{SRP}_{ij} = \frac{\mathrm{RP}_{ij} - \bar{\mathrm{RP}}_J}{\sigma_J} \tag{2}$$

where SRP_{ij} = standardized risk perception score for participant i for photo j; RP_{ij} = raw risk perception score for participant i for photo j, $\bar{\mathrm{RP}}_J$ = mean risk perception score for photo j for all participants who encountered photo j, and σ_J = standard deviation of all risk perception scores for photo j for all participants who encountered photo j

Table 4. Pattern Matrix from Iteration 3

	Component		
Emotional state	1	2	3
Joy	−0.891	−0.154	0.092
Happiness	−0.828	−0.202	−0.009
Amusement	−0.807	0.084	−0.092
Interest	−0.725	0.114	−0.032
Fear	0.029	0.853	−0.007
Anxiety	0.041	0.792	0.065
Disgust	−0.014	0.784	0.022
Sadness	0.048	−0.092	0.917
Unhappiness	−0.017	0.208	0.793

Testing for Differences in Risk Perception among Emotion Groups Using a Kruskal-Wallis Test Followed by Multiple Mann-Whitney U Tests

Participants were split between the three emotional groups found by PCA and a neutral control group based on their scores from the Rottenberg et al. (2007) emotional state questionnaire.

These groups included neutral, positive (amusement, happiness, interest, and joy), intense negative (fear, anxiety, disgust), and mild negative (sadness, unhappiness).

Because of wanting to test for differences in risk perception between the four groups (six combinations), a Kruskal-Wallis test, the nonparametric equivalent of ANOVA, was first used in order to account for the inflation of type I error when making multiple pairwise comparisons. The test provided very strong ($p < 0.001$) evidence that at least two of the four emotion groups differed in terms of mean risk perception. Multiple Mann-Whitney U tests were then used to determine where those differences in risk perception lay. An advantage of the U test lies in its robustness to outliers because it transforms the data to ranks. Assumptions of identical shapes of the distributions for the two groups were met in every case. A U test's null hypothesis is that *the difference in the two population mean ranks is due to random sampling, assuming that the two populations have identical distributions*. The following statistically significant differences in risk perception scores were obtained:

- Positive group and intense negative group ($p = 0.003$);
- Positive group and mild negative group ($p = 0.003$);
- Neutral group and intense negative group ($p = 0.011$); and
- Neutral group and mild negative group ($p = 0.02$).

Statistical differences between groups were measured in terms of distance from the mean in units of standard deviation. The sign of this value (±) represents whether the risk perception average is above or below the mean. As one can see in Table 5, the positive and the neutral groups averaged respectively 0.35 and 0.32 standard deviations *below* the mean, indicating that these groups perceived a relatively low amount of risk. Alternatively, the intense negative and mild negative groups averaged approximately 0.24 standard deviations *above* the mean, indicating relatively high-risk perception scores. Further, an analysis with the risk perception scores divided by the median risk perception scores for each corresponding picture revealed that individuals in the positive and neutral groups perceived, on average, nearly three times and a half less construction risk than the individuals in the two negative

Table 5. Descriptive Statistics

Group	Mean	N	Minimum	Maximum	Variance
Positive	−0.3480	25	−2.38	0.77	0.416
Intense negative (fear/anxiety/disgust)	0.2322	18	−0.90	1.04	0.274
Mild negative (sadness/unhappiness)	0.2523	22	−0.76	1.49	0.358
Neutral	−0.3238	8	−0.82	0.12	0.124

Note: Mean, minimum, maximum, and variance values are in units of standardized risk perception; N is the number of subjects.

groups ($p < 0.01$). Such a huge difference is alarming and warrants future inquiry.

Limitations and Justification

First and foremost, the subjects of the experiment were students, not workers. Even though they belonged to the civil, environmental, and architectural engineering department, and 45% already had at least one significant construction site professional experience such as a summer internship, it needs to be acknowledged that students represent a population very different from construction workers. However, using students with a sufficient amount of experience and knowledge of construction sites, but without enough experience to be biased in their risk perception, allowed observation and investigation of the phenomenon desired by the authors (impact of emotions on construction risk perception) with an enhanced signal-to-noise ratio. This experiment is not concerned with the possibility that students could have overestimated construction risks due to their lack of experience, because the differences between groups would have remained the same, leaving the results and inferences unchanged. For these reasons, the results are theoretically generalizable to construction workers, but future research should be done to confirm this belief.

Second, the subjects all shared the same occidental Anglo-Saxon culture, which could prevent the generalization of the results to, for instance, Hispanic workers. However, psychologists broadly agree that emotions are cross-cultural (Elfenbein and Ambady 2002) because they are biologically programmed (Matsumoto 1989). Furthermore, Russell (1994) argued that broad emotional dimensions, such as valence (positivity or negativity of emotions) and intensity, are universal.

Third, according to Comrey and Lee (1992), a sample size between 50 and 100 subjects is not ideal when using PCA. However, Preacher and MacCallum (2002) argued that as long as the communalities are high and the number of factors is small (which was true in this case), researchers should not be concerned about small sample sizes. Similarly, according to Costello and Osborne (2005), high communalities without complex variables and several variables loading strongly on each factor is a sign of strong data, regardless of the sample size. As previously discussed, the communalities were very high; therefore, this relatively small sample size does not affect the validity of the results.

Fourth, the results reveal an association between subjects' self-reported emotional states and their risk perception but not a causal relationship. In fact, the findings do not statistically allow the conclusion that the differences observed in risk perception are *caused* by emotional states, even though prevailing literature overwhelmingly supports this inference. Consistent with methods used in psychology, a manipulation check was conducted to statistically demonstrate a causal relationship using a linear regression on complex orthogonal contrasts that correspond to the target emotions in the film clips (Davis 2010). Unfortunately, although the excerpts induced strong positive and negative emotions, they did not completely succeed in eliciting their *target* emotions. Therefore, the contrast codes and manipulation check could not yield meaningful results. Thus, causal inferences were not made, and associations with strong theoretical support from past literature were reported instead.

Fifth, the selection of emotion-inducing film clips was limited by the relative old age of the movie batteries that were available in the literature. The authors had in mind very recent movies which would have elicited much more powerful emotions. Advice for future research is thus to develop and validate a custom movie clip battery a priori. There was not enough time and resources to do so in this study.

Finally, although self-report ratings are widely used in psychology to assess emotional states, this method has some limitations. First, people differ in their use and understanding of the emotion language. The extent to which people are able to conceptualize their emotional experiences varies as well. Consequently, recommendation for future studies is to use objective methods such as hidden camcorders (facial behavior and body movement measurement) or eye-tracking devices (startle response measurement), in addition to self-answered questionnaires.

Conclusions, Contributions, and Recommendations

The findings contribute to an ongoing debate regarding the relationship between emotions and risk-taking behavior, corroborating some theories and contradicting others. Specifically, the results support previous findings that emotions are used by individuals as a source of information about the riskiness of their environment (Johnson and Tversky 1983) and that specific emotions such as anxiety and fear lead to the activation of self-protective processes (Öhman and Mineka 2001). If, based on the findings, it is assumed that risk perception is inversely correlated to risk-taking, the results can be extrapolated to corroborate Yuen and Lee (2003), who found that negative emotions are linked to risk aversion, and Isen and Patrick (1983), who found that positive emotions are associated with risk-taking.

The chief theoretical contribution is that the impact of emotions on risk perception in an occupational-like context was measured for the first time. Additionally, this is the first study to implement a rigorous process for measuring emotional states, measuring relative risk perception for realistic environments, and statistically relating these scores through a dimension reduction process and pairwise comparisons between independent groups. The results increase the comprehension of how emotions may antecede risk-taking behavior, knowledge that is critical to eventually understanding, within the situational awareness framework, how to prevent undesired risk-taking behavior in highly consequential environments.

The practical implication of this study is that workers in positive and neutral emotional states may act upon risk perceptions that are significantly lower than their counterparts in negative emotions. Although it would be absurd to recommend activities that regularly place workers in negative emotional states, these findings may mean that pre-job safety meetings should include sober and honest descriptions of the potential outcomes associated with an injury.

Discussions of potential impacts of injuries on family, for example, may place workers in an emotional state that is more conducive to safe behavior than a light-hearted discussion or jokes about safety. Thus, emotional intelligence should become a must-have skill among safety professionals and site supervisors in general.

In light of the encouraging findings of this exploratory pilot-study, future research that validates these findings with a larger and more diverse group of participants is suggested. Specifically, it is recommended to repeat the experiment with construction workers, as well as collecting more data, in order for strong predictive models to be built. Additionally, extending testing to the relationships between emotions and other aspects of situational awareness such as hazard recognition and the cognitive processes of decision making is recommended. Although studying risk perception is a worthy inquiry, fully understanding the impact of emotions on unsafe work behavior will require this additional research.

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