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ASSESSMENT OF CONSTRUCTION WORKERS' RISK PERCEPTION AND VISUAL ATTENTION TO IMPROVE SAFETY IN CONSTRUCTION INDUSTRY

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ABSTRACT

Recently, the construction industry has implemented different approaches to improve safety among construction workers, however; only a few of them have focused on human factors. The main objective of this study is to investigate the role of human factors on safe behavior of construction workers at the job site. The study is conducted through three-steps to analyze the relationship between worker's safety visual attention and perception of risks and hazards. The three-step experiments include questionnaire, Balloon-Analogue-Risk-Task (BART), and eye tracking assessment.

In the first step, the questionnaire is conducted to assess participants working experience and knowledge and psychologically measure their safety attitude and risk perception. In the second step, a BART test is conducted to measure risk taking behavior. The last step measures the construction workers' visual attention using eye-tracking. Eye-tracking is widely accepted as the most direct and continuous measure of attention given that where one looks is highly correlated with where a person is focusing his/her attention on. In this project, the participants are selected from construction workers and managers from different companies as well as Architectural Engineering undergraduate and graduate students (Construction option) who have worked on construction projects.

The results of the survey analysis reveal that experienced workers and those who have more children have a higher risk perception compared to the less experienced workers. In addition, descriptive statistics reveal that most of the workers are concerned to get injured at work. This could confirm that the construction workers positively perceive risks and hazards at the job site. Also, construction workers who are taking greater risks (based on the results of the BART experiment) have lower risk perception and, they would underestimate the level of danger however, those who are less risky have higher risk perception and they would overestimate the level of danger.

Keywords: Eye tracking, Questionnaire, Risk, Construction hazard, Safety.

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Chapter 1

Introduction to the research

Motivation

The construction industry is well-known for being a dangerous or highly hazardous industry, due to the high number of accidents and fatalities that occur on construction sites around the world. The risk of major injury in construction industry is approximately three times higher than in the manufacturing industries. In addition, the risk of fatality is around five times higher (1). These fatalities and injuries in the construction sector are very costly to the United States' economy due to loss of time, worker's compensation costs, and loss of productivity, and have emotional and psychological burden for workers' and their families.

Unfortunately, tens of thousands of construction workers are injured on construction sites each year. In 2010 more than 195,000 injuries occurred. In addition to injuries, on average over 1,000 fatalities happen each year. In 2014, according to Occupational Safety and Health Act (OSHA), 4,821 workers died on the construction sites (3.4 per 100,000 full-time equivalent workers), which is more than 92 deaths per week, or more than 13 deaths every day.

Although Occupational Safety and Health Act (OSHA), which was passed by Congress in 1970, has improved construction sector's safety and health records and consequently number of accidents have decreased, great number of fatalities and accidents still occurs on construction sites (2). In order to address this issue, considerable progress has been made to improve the workplace safety and consequently the fatality rates have decreased by 25% (3).

Generally, accidents at work happen either due to: lack of knowledge or training, lack of situation awareness, lack of supervision, lack of attention to follow the task safely, or the lack of sufficiently controlled a working environment (4). In construction, unsafe behavior is one of most important factor of accidents (5). Based on the information given by Health and Safety at Work (HSE), about 90% of all fatal construction accidents could have been prevented; 70% of them by effective management action.

The effectiveness of human behavior in construction industry plays an important role and requires detailed knowledge and understanding of:

(a) How a hazard and risk is perceived

(b) How a seen hazard is recognized, and,

(c) How a decision must be made to avoid the hazard based on the risk tendency and personality (6).

Also, safety decision or hazard identification by occupants is made in very short periods of time and it makes the role of attention very important in the present study. The perceptual process explains how a person takes sensory information (information collected from person's senses such as sight, hearing, and smell), or stimuli, from the environment. Attention explains how a person selects information for more extensive processing. Attentional process plays a much greater role when the decision must be made in a short period of time (e.g. in risky and hazardous situations), usually less than 200 ms. (7).

According to Ramsey (8), workers act based on their risk and hazard perception at the jobsite, so safety improvement in the construction industry is the most appreciated beneficial effect of enhancing worker's risk and hazard perception. Therefore, systematic understanding of unsafe behavior has great potential to contribute to the reduction and prevention of injuries and fatalities in construction projects.

Therefore, the main goal of this project is to investigate the role that human behavior play in accident causation by understanding their risk and hazard perception based on their socio demographic variables and hazard identification ability (visual attention).

Defining and Discussing Safety Attitude, Perception, Culture and Climate

According to Ramsy (8), attitudes are defined as, “a tendency to react positively or negatively towards an objective or person.” Porter et al. in 1968 (9) on the other hand, explain attitudes as, “either explicitly or implicitly related to people, events, actions, ideas or institutions” In 1948 (10) argued that, “attitudes are relatively enduring, and that, if you know a person’s attitudes, you can usually predict what he/she will say or think in future reactions to that objective or similar objects.” Therefore, attitudes would be based on some underlying physiological and experimental system ‘inside people.’

The concept of safety attitudes is an abstraction, related to persons’ behaviors, statements or opinions, and presumably, experiences and beliefs. The definitions given depends on what observables are selected. So, the “safety attitudes” must be considered a complex and multi-dimensional concept. On top of that, authors such as Krech and Crutchfield (10) argue that safety attitudes have an emotional or affective aspect which contains positive or negative feelings of the object of ‘safety behavior’ in construction; conative aspect such as a tendency to act in a specific way toward construction aspects; and cognitive aspect such as beliefs or idea about it.

In understanding of safety culture and climate, the perception and attitudes of the workforce are important factors in assessing safety in construction job site. Attitudes are defined as “a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor” (11). According to the study conducted by Griffin and Neal (12) the attitudes and perceptions of safety should be obviously different issues. Attitudes are influenced by individual’s differences besides environmental factors, so attitudes measure greater variability in comparison with perceptual measures. Neal and Griffin defined safety perception as “how workers view safety related policies, procedures and other workplace attributes concerned with safety."

A number of studies found showing that attitudes and behaviors are significantly associated (13), (14). Theory of reasoned and planned behavior, studied by Ajzen and Fishbein (15) show that attitudes and behaviors are related to and demonstrate relationship between health attitudes and risk behavior (15) Health related beliefs and safety belief could be similar since they might affect individual's health. This theory demonstrates that most people behave sensibly; which is, they deliberately use information from their surrounding and consider the implications of their actions.

This research has set out to study "safety perception" and "risk behavior" in terms of variables selected as factors of influence on the safety on construction related to human factor.

Defining and Discussing Risk Perception

There are different definitions for risk; risk is defined as "*event combination of likelihood and consequences*" (16). The International Organization for Standardization (ISO) at the International Electro Technical Commission (IEC) (ISO/IEC) defines risk as a "combination of the probability of occurrence of harm and the severity of that harm" (17, 18), where the "*physical injury or damage to the health of people, or damage to property or the environment"* (17, 18) related to this risk definition is also hazard; "*potential source of harm"*(18). So, in defining risk to explain factors that make an unwanted consequence, some terms such as harm, hazard and threat are commonly used.

The subjective likelihood of a negative event is defined as a risk perception (19) . Rohrmann (20) defined risk as a personal evaluation of the likelihood of incident of an unwilling outcome. Risk perception is closely related to the concept of risk. Thus, understanding perceived risk plays an important role in study of risk analyses (21). According to Lindoe (22), perceived risk (the fear and dread when a hazard is being felt) and assessed risk (quantifying risk through rational analysis and measures) might be two kinds of risk. Risk perception could be different among individuals. Also, risk assessment might be arguable and questioned, but it will be more objective than risk perception.

To recognize what is acceptable and what is unacceptable risk, one could ask, "*How safe is enough?"* (23, 24, 22). According to ISO/IEC tolerable risk is "*risk which is acceptable in a given context based on the current values of society"* (18). This concept is important because individuals's tend to tolerate higher risk if they have some form of control over it (e.g. as a part of their task in construction site), than if they have no control over it (e.g. as a member of general public). This is valid for both perceived and assessed risk.

This study examines construction industries' risk perception and risk taking tendency based on participants'' sociodemographic variables and their construction hazard identification ability (visual attention).

Visual Attention

Visual attention is the ability to interpret the surrounding environment by processing information through sight. The process of choosing "what" to observe is selective. Our eyes do not have enough attention to focus on every object in the field and gather information. Therefore, it is important to select the essential region for processing. Visual selection has different characteristics, such as how it occurs and when it occurs. In addition, visual selection occurs in multiple phases. The first phase is an overt action, which is performed by eye movement to identify a location of interest. After the eyes have moved to a location of interest, a covert selection occurs. In covert selection, our eyes do not move, but our attention actually shifts to various aspects within our field of vision, such as colors, shapes or words. In addition to overt and covert phases, there are two types of visual selection, spatial selection and property selection. Spatial selection focuses attention on a fixed region. Different aspects and objects in the location of interest would be examined. On the other side, property selection selects features of an object. During the limited time of visibility, even though our eyes do not have time to select objects and process information in extend detail, it is enough to generate an image on the retinas with visual information. Moreover, visual selection is defined based on the importance of the objects in the visual field. Some objects are innately more important. For example, moving objects are essential for survival; therefore, they naturally have a higher priority than stationary objects. The level of importance of an object is also based on personal experience (25).

Research Objective

The goal of this project is to investigate the role that human factors play in construction accident and to gain an understanding of their level of influence on construction site safety. During this process, the following objectives will be addressed:

I. Understanding construction workers' risk perception.

II. Understanding construction workers' hazard identification (visual attention).

III. Understanding relationship between sociodemographic variables and construction workers' perception of risk, hazard and visual attention

Research Design

This thesis is organized into 6 chapters. The introductory chapter outlines the research problem addressed by this study. It also sets out the objective of the study and includes brief definition of related key words of the study.

Chapter 2 is the literature review of the study, which reviews previous studies related to safety perception, safety management, factors affecting construction safety, eye tracking and model accidents.

The methodology used in the study is discussed in the chapter 3. This chapter covers the scope and objective of the study, research hypothesis, and explains the steps of the methodology in a framework format.

In the chapter 4, which is entitled assessment of construction workers' risk perception, the questionnaire related to the risk perception is designed and analyzed. Then in Chapter 5, construction workers' visual attention is studied which measures and discusses visual attention. At the end, the obtained data are analyzed in the chapter 6.

Chapter 2

Literature Review

The literature review is based on upon material searched, and researched through the duration of the study. Material reviewed both in published and unpublished work. The literature search and review has aims: to introduce a broad or general background to the subject matter as covered by the researcher, in terms of reading and consultation, also the literature assisted this study in the formulating and developing a research framework, and methodology.

In the main, a literature review provides the study with the basis for a clear understanding of the importance of safety in construction study, the importance of safety managements, factors affecting construction safety such as safety training, human behavior and using new technology in this area. In addition, using existing knowledge related to measuring visual attention and risk perception with the eye tracking technology assisted this study in shaping the framework and methodology.

Safety in Construction

According to the General Duty Clause of OSHA in section 5(a) employers are responsible for providing a safe working place where employees could recognize a hazard easily and be able to prevent death or any physical injuries (26). This results in a huge responsibility for employers to recognize and reduce any hazards and risks situations that may cause physical injuries and death. (27) Friend argued that safety professional as the person responsibility for helping management identify, measure and control hazard in the work place. Most of construction companies have their own ‘in-house’ safety experts that are responsible for safety training and programs to minimize loss exposure in the workplace.

In addition, financial issues motivate companies to provide effective safety program to mitigate workplace injuries and fatalities. For example, safety record of construction company is used by some customers for awarding contracts (28) or the annual worker’s compensation insurance policy rate will increase with higher number of fatality and injury rates.

According to Sawacha (4), accidents at work occur because of lack of worker’s knowledge or training, lack of management, lack of implanting safety, worker’s errors and careless, and the lack of environmental issues. On top of that, in construction, unsafe behavior is tending to be the most importance factor in the cause of accidents and also suggests a poor safety culture.

Therefore, the goal of this research is systematic understanding of unsafe behavior which has great potential to contribute to the reduction and prevention of injuries and fatalities in construction projects.

Risk and Perception of Risk

Any activity has the potential of having risk. (29) Hallowell argues that complete cancellation of risk is impossible. On top of that, Caplan (30) generated a mathematical formula which defines risk as hazard divided by safety measures. Based on this concept, we can decrease risk by increasing safety measures; however, we are not able to removal risk totally.

According to Stewart (31) there could be a relationship between safe behavior and perceived risk. Workers’ behavior should be analyzed in relation to their perception of risk (31).

The level of perception of risk is also related to a self-protective behavior (32). On the other hand, (33) claimed that, the worker's experience also impacts their risk perception.

The perception of risk can be changed over the time in a person. In addition, different people have different perceptions of risk (34). Many studies (35, 36, 37, 38) have indicated that experience of having an accident and their consequences (i.e., suffering and injuries) change workers' perception of risk.

The other factors that may affect risk perception are the sociodemographic variables. The relationship between sociodemographic variables and risk perception has been studied from different standpoints. These factors are age (39), schooling (19), income (40), training (41) and (42) , gender, ethnicity and socio-economic status (43, 44). Although, many studies have examined perceived risk, not many studies have worked on construction industry, even less studies focused on disciplines such as ergonomics and hygiene. So, this study address this problem by analyzing the perception of risk in the construction industry.

Risk assessment is another important issue. Effective assessment of risk is important for controlling risk (45). Risk assessment includes, identification of hazards at work, leveling the risk from the hazard, making decisions for controlling risk, and performing a control strategy (45). Two key approaches for risk assessment are qualitative and quantitative assessments. If we can measure the probability and consequence of a specific risk situation, the risk could be ordained in a numerical term (46).

Safety Management Program

There are different approaches for safety management and analyzing safety data. Some approach used software driven programs while others used manual tracking systems. Hallowell (2) have suggested that most effective safety management programs include upper management support with commitment to strategic sub-contractor selection. In addition, record keeping, accident analysis and emergency response planning were determined to be less effective. Choosing specific safety elements for a safety management program is irregular. In another study, (29) analyzed risk levels for various activities which helped safety management planners to make suitable evaluation to implement safety elements that have the possibility for risk reduction. Consequently, this risk level evaluation practically could validate a risk-based safety and health analytical model for evaluating expected risk with specific worker's activities. In additions, it can be useful for strategic selection of the most influencing safety program.

Developing a uniform policy for on-site safety management seems to be a complicated task. For example, the American Society of Civil Engineers (ASCE) developed an on-site safety policy and clearly assigned some safety responsibilities to owners and design professionals whereas the trade organization assigned base responsibilities to the general contractors. However, Occupational Safety and Health Act assigns principle responsibility to employers and the employees who are exposed to dangers (47).

In addition to policy of safety management, the quality, environmental and safety (QES) safety management system has been accepted by different contractors. Koehn (48) analyzed this system and argued that performing an efficient safety management program accounts as a top down process. In this program, top management, a line management and other employees working as a team, work and organize the program and then convince all employees to accept the process. Another study on safety management done by Garrett (49) focused on human factors analysis classification system (HFACS) . HFACS is mainly organized for evaluating the human causes of accident for rail, air and offshore environments. They presented the human error awareness training (HEAT) implications to the construction sector.

In conclusion, there is a notably general accepted approach to safety management in construction sector; specifically, in the field of primary responsibility for the safety. According to the literature, some managing safety systems and approaches are available, yet more caution and attentive study of the applications should be practiced for ongoing evaluation and improcment.

Specific Safety Elements/ Factors Affecting Safety Performance of Construction Industry

Many studies report safety elements but most of them are general in nature and seem to be difficult to measure, such as inspecting dangerous situations, safety organization, safety policy, plant and equipment maintenance, high risk times, individual competence and management behavior. Although, these are important safety elements, in order to use them as a predictor of a safe working area, converting them to the measurable formatted make them easier to measure.

Among the aforementioned elements, safety training is considered one of the most important safety factors. Most projects provide safety and health training, but still they cannot quantitatively evaluate training programs in order to reduce dangerous behaviors and increase proactivity (50). This can be attributed to the general approach to safety and health training which does not help workers and managers in different working environment to recognize and measure safety elements. To find the causation of unsafe behaviors, individual and environmental conditions that significantly affect safety awareness and safety behavior must be identified (51).

Some other studies focused on safety records and rating system. Rajendran and Gambatese (52) provide a rating system to evaluate projects based on the importance of construction worker safety as well as the degree of performance of safety and health factors. They used the Delphi survey to validate 12 experienced safety and health professionals representing different sectors. Consequently, 50 safety and health elements were organized into 30 categories. The results of their Delphi panel show that the safety incentive is an important element.

In addition to training, people recently have explored technologies to develop a secure and jobsite safety. (53) reported a set of the specific safety elements which measured the impact of a radio frequency sensing device to alert workers-on-foot and equipment operators when they are in a very proximity risk or dangerous situation, which could result in a serious injury or a fatality.

Although there are many safety elements reported in literature, their effectiveness for predicting a safe working environment in construction is hard to quantify. Some projects perform safety elements that have a particular impact on reducing fatalities and injuries; on the other hand, others are performing safety elements that have little impact on decreasing fatalities and injuries.

Human Factor

The human factor is a key element in preventing accidents. Preventing accidents identified by the Accident Prevention Unit (54) includes ensuring that the working area is safe enough by providing protective equipment, clothing and training workers. Therefore, the main player in accident prevention is the human factor. On top of that, construction workers must know the cause of accidents in the jobsite to eliminate and prevent accidents (55).

Behavior is an important aspect of the human factor in construction safety. It hinges on construction worker's decision that result in their working in a safe or unsafe manner. Thus, it is important to determine why workers engage in risky behavior. Choudhry and Fang (34) human behavior study found related human factors, such as lack of awareness, work pressure, colleague attitudes, organization, economic issues, and psychological factors. Also, they identified the method based on subcontractor's recommendations to improve the site safety. Because subcontractors mostly control different situations at the job site, they have a good judgment on best action, risky and hazardous situation.

As mentioned above, human behavior is one the influencing safety factors. Ramsey's accident sequence model (see Figure 2-1) presents the way that hazard is perceived based on the sensory skills, how the hazard is understood, and how risk tendency affect decision making in order to prevent accidents (6). Individuals tend to identify hazards and making a real-time decision. In this situation, they use their experience and sensory information, which is taken from a person's senses such as sight, smell and hearing. A person's attention presents the way that person selects the information for more extensive processing Attentional process plays a much greater role when the decision must be made in a short period of time (e.g. in risky and hazardous situations), usually less than 200 ms. (56).

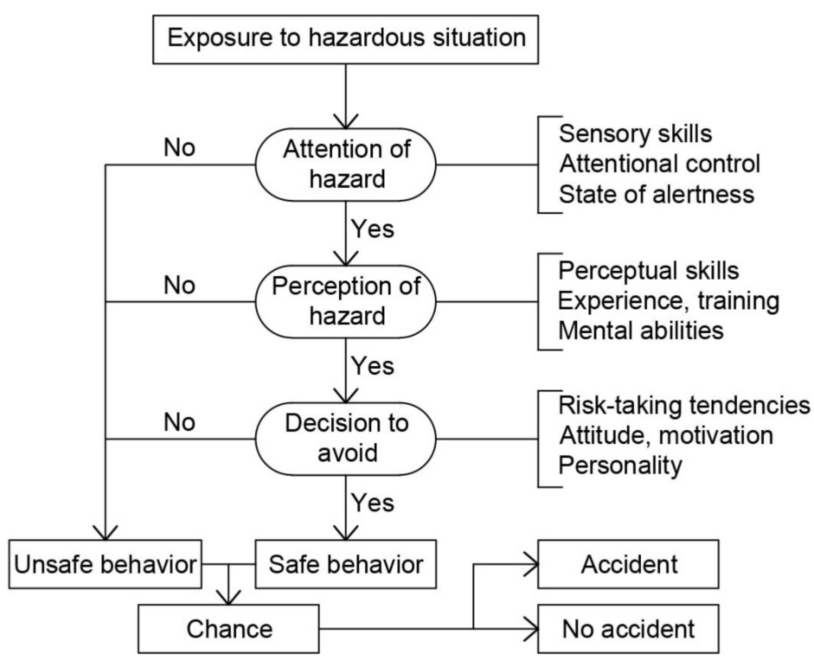


Figure **2- 1**: Accident sequence model representing various stages in the occurrence or avoidance of accident (6)

According to behavior models, workers are the biggest influencer in accidents (57). Also, human unsafe personality seems to be responsible for making errors in different situations (58). (59) conducted a case study on accidents that happened in the construction sector in U.S. They found there is a strong relationship between workers' behavior and the level of accident injuries. Most of the accidents (80 to 90 percent) happened because of unsafe workers' behavior and performance. In the psychological and behavioral study done by Quinn (60), demographic information of field and office personnel of a construction industry was analyzed. The results showed that, 56.3 percent of accidents happened due to a lack of attention or awareness. In addition, twenty jobsites were visited and eighteen general contractors and subcontractors were interviewed in order to understand both causes of and solutions of accidents on-site for construction workers. Most of the results from the interview revealed that lack of training, lack of attention to safety, and negligence play essential roles in accidents in construction site.

It is important to consider the role of humans in any health and safety initiative which includes:

1. Human error: workers behave through their risk perception at job site. In addition, their response and perception of risks affect their way of working, pursuant actions, human error, misjudgments and wrong actions, finally result in injuries (61, 49). Previous studies also showed that the beginning of the working week is more prone to accidents, possibly because after the weekend break, worker's safety awareness is decreased (62, 63).

A very close look at any system shows that the human as an operator plays an important role. In a study conducted by Howland, it was found that human "operators" are responsible for accidents (64). He mainly studied the causes of failure which can be due to human error and the result of psychological and ergonomic factors. Also, human error happens because of lack of incentive, incompetence, stress, social behavior, lack of knowledge and training as well as illness. On the other hand, (65) conducted research on the relationship between risk perception and human error. It was found that people who cannot perceive a risk, tend to make a weak decision which can affect the safe operation of the system.

2. Relationship with colleagues: previous study conducted by Debrah and Ofori (66) showed that workers who have better relationships with their colleagues have fewer incidents. Workers who feel that their employers are concerned with their safety have better safety records.

3. Immigrants: foreign migrant workers are more in danger of accidents, mostly due to lack of effective communication at the workplace and difficulty in understanding safety rules (66).

4. Insufficient safety training and education: In many countries, such as China and Australia, many accidents happen due to managers and worker's lack of safety training and knowledge (67). In Hong Kong, one problem is the method of training safety. Most new workers are trained by an experienced master. Such apprenticeship does not make an efficient educational system and is different from individual to individual (68). In Singapore, many untrained foreign workers who were fisherman or farmers were trained, but they left the country after two or three years of working. Consequently, managers and contractors are not willing to invest their money and time for safety training and education on a constantly changing workforce.

5. Fatigue: In a recent study in China researchers found that almost 80% of stakeholders account fatigue as the most important factor resulting in serious accidents (69).

6. Workers' tend to achieve short term benefits: such attitudes make worker's risk perception lower and make them underestimate their job's risk level. (70).

Safety training

Safety training is required in order to provide a strong safety culture for improving safety knowledge at construction sites (12). According to (71), workplace training is mainly for educating adults from different backgrounds who will challenge different situations. This is mostly important for construction sector since the challenges and work environment have changed rapidly (34) Since the number of injuries and fatalities happening in the construction sector is significant, Wilkins (71) emphasized the requirement and necessity of training for this sector. Additionally, he claims that the main reason could be the lack of safety procedures and inadequately delivered safety training. A study carried out by Choudhry (34) argued the effect of a one-hour hazard awareness training session which is provided by union-based apprenticeship program. The training provides a considerable improvement in the attitudes and knowledge about the workplace. Griffin and Neal (12) expanded on this by their study on improving safety knowledge. They showed that safety knowledge is not only related to safety compliance, but also positively related to safety participant.

Wilson (72) showed that 93% of owners and site managers believe that human factors are the most significant reason of accidents rather than working conditions. He founds the key impact of professional development and training of the workforce on decreasing number of accidents. Also, he commented that there is not credible safety legislation to understand and implant it effectively. In addition to the recommendation for the improvement within the industry, Wilson (72) suggested to improve legislation to be more understandable to the layman; make the formal training more accessible, improve the level of education, and improve the way of passing on safety information. In the last two decades, some of Wilson's agenda was reformed and has helped to reduce accidents injuries, and fatalities.

Occupational Safety and Health Administration (OSHA) offers a wide selection of training materials and resources in order to elevate workers' and employers' knowledge on recognition, avoidance, and prevention of safety and health hazards in their workplaces. OSHA collected different training provisions into a single report to make it easier to place them in the different standards (73). Most of the standards are quite explicit about what safe practices should be trained. OSHA's safety and health standards, including those for asbestos, fall protection, cotton dust, trenching, machine guarding, benzene, lead and blood borne pathogens have prevented countless work-related injuries, illnesses and deaths. Nevertheless, far too many preventable injuries and fatalities continue to occur. Significant hazards and unsafe conditions still exist in U.S.

Technology in construction

In addition to training, researchers recently have used different technologies to develop a secure and safe jobsite. Computers and information technologies provide support for safety training. For example, Wallen and Mulloy (74) present computer-based safety training methods; Cheung et al. (75) developed a Web-based safety and health monitoring system for safety training; and Benjaoran and Bhokha (76) developed 4D CAD technology for safety management.

One of the new technologies in construction safety, with the aim of practicing safety training, is gaming technology. The development of game technology has grown by the video game over the past two decades. Because of its unique characteristics which is interactive, intelligent, multi-user and open-source engagement, many academics and practitioners use game technology to improve training, simulation and education performance (77). Examples include simulating human behavior (78), human–robot interaction (79), laboratory accidents (80); food safety (81); virtual museums (82); and visualizing landscapes (83).

Some studies have been conducted to implement safety technologies in construction-like environments to improve workers' safety. Ruff (84) presented that existing off-the-shelf Radio Frequency identification (RFID) technology did not address the requirements for the harsh mining environment. National Institute of Safety and Health (NIOSH) created a prototype called HASARD (Hazardous Area Signaling and Ranging Device) that uses active RFID technology consisting of a tuned loop antenna (transmitter, electromagnetic signals) on the equipment and receiver worn by a worker (85). The system triggers alarms when a transmitter interferes with the receiver.

Visualization technology has been applied in construction management research for the whole life cycle assessment. As for safety control, visualization have been useful in design phase to help all participants in identifying and solving construction problems (86, 87). 4D CAD technology have been applied to identify workspace congestion to determine potential safety hazard on the job site (88). In addition, (89) BIM-based 4D models created in the design process could be helpful in site safety planning in later phases. Also, virtual construction simulation could be used for collision detection in the construction phase (90). With considering operation safety issues, a practical methodology for integrating visualization and simulation for crane operation in construction was developed to assist practitioners in construction planning (91).

The construction site is a dynamic and complex environment and needs hours of attention, thus, some situation awareness techniques could be helpful. Williams et al. (92) showed that eye-tracking technologies can be used to measure the attention and perception components of situation awareness. Since cognition, eye movement and gaze patterns have correlations, they have been useful in human factor related research. Eye tracking technology could serve as a quantifiable connection between a person’s cognitive process and his/her brain activities, such as perception and detection of the environment (93). They used mobile eye- tracking technology to collect real-time data from the eye-movement patterns from construction workers. Also, (94) used remote eye-tracking technology in order to evaluate construction workers hazard identification skills by showing them different images of construction hazards.

Eye Tracking

The human eye has limited capabilities and it needs to constantly scan the field of view to focus on the area of interest (95). Previous studies showed that there is a strong relation between perception and attention which is often directed at the area being seen. It was also shown that people focus more on areas that contain more information of interest (96)The same study also showed that eye movement paths have considerable correlation with the observer intentions. This relationship led to adaptation of eye-tracking research for many academic and commercial purposes such as advertising, design, and psychology (97). Eye-tracking studies largely investigate the eye movement to infer certain relationship in areas of interest.

Human Computer Interaction

There are two main viewpoints associated to Human Computer Interaction (HCI); the first is the perspective of information processors and the second is interacting across a user interface (98) The study of human behaviors related to HCI interactions is of particular interest in the field of computing due to the valuable insight they can provide. One of the most important elements in HCI is human eye movement. For example, it was shown that many groups of computer users can receive up to 80 percent of their perceptual input via the visual channel (98). Techniques for studying eye movement behavior are considered an effective means of characterizing HCI. The significance of eye movements to evaluate human performance is that they provide measurable and observable data. These data have a predictable relationship with cognitive processes related to visual attention which are not thoroughly understood. However nowadays, technology brings an opportunity to measure visual attention. One of this sophisticated technology is eye tracking. Eye tracking can measure number of fixations, gaze durations, and scan paths (98). Eye tracking technologies continue to become more portable, more accurate, less intrusive and less expensive and thus a more practical supplement to traditional usability testing techniques (99) Eye tracking produces a large amount of data, leaving the test administrator with many options in terms of analysis. The experimenter can compute information such as fixations (i.e., eye's focus on a single point), scan paths (i.e., order in which multiple fixations occur), and the number and duration of dwells (i.e., consecutive observations in the same region) on areas of specific interest to the experimenter.

Neurological Background: The Eye

There is much neuroscience literature focusing on human visual system and most of these studies focused on the eye (100). The first step in human vision begins when rays of light hit an object and are reflected. A human who is looking at the object absorbs the light energy through the eye. The process of absorption hereby proceeds through the cornea, the iris, the lens and the retina (101) The cornea acts as an outer protective layer for the eye; it also reflects some of the light, which is known as corneal reflection. The main function of the lens is to focus the light rays, and the iris is regulating the amount of light energy that can surpass the lens on the retina (102), where an upside-down image of the apple is created (Figure 2-2).

Next, the retina located at the end of the eyeball converts the absorbed lights into electrical impulses by photo-sensitive receptors – 120 million rods and 7 million cones. Rods are used to capture dim and achromatic light, whereas cones are used to absorb chromatic light. The next layer of vision is 120 million photocells that are merged to 1 million fibers via ganglion cells (103) In this step, the fibers are bundled again to one optic nerve connecting the electrical potentials to the brain and they are processed. The fovea is responsible for sharp central vision which is necessary in humans for activities where visual detail is of primary importance, such as reading and driving. The visual angle foveal vision is only approximately one degree. As a practical example, the area that a human eye resolves in color and high resolution is approximately equivalent to the area of one's thumbnail held out at arm's length. Due to this limitation, we have to rotate our eyes in their sockets, positioning the eye such that the area of interest in the world is projected onto the fovea. This movement called a saccade and is usually very fast, up to seven hundred degrees per second and typically lasting for thirty milliseconds.

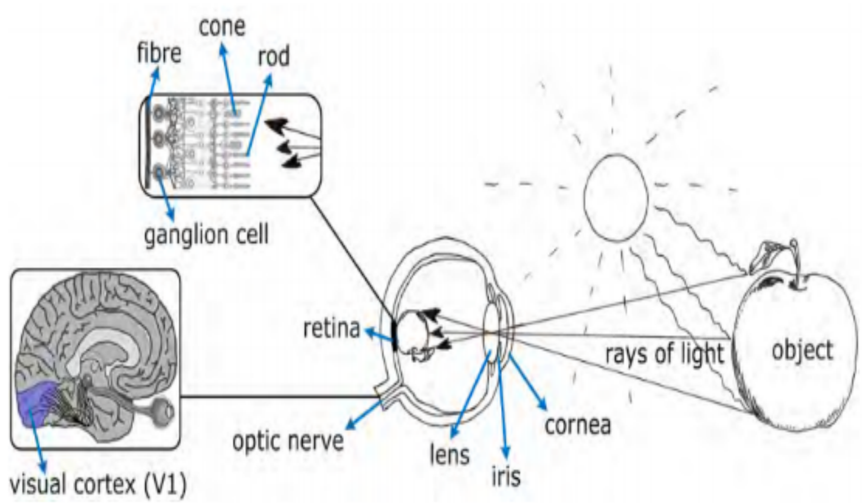


Figure **2- 2**: Visual System Process.

Eye tracking

Modern eye tracking uses a combination of hardware and software to determine the location of the user on a given interface or scene. Eye tracking was originally introduced over 100 years ago by Dodge and Cline (104). They used an invasive procedure that involved direct physical contact with the eye. This type of experiment, one could only imagine, would disrupt the participant's natural behavior. Eye tracking has since evolved and below we present a comprehensive overview of the eye tracking history and methodologies.

History of Eye-Tracking Research

Eye tracking has a 100-year history going back to late 19th century (99). In the past, determination of areas of interest was the main goal of eye-tracking research. Technological advancement in recent years has considerable impact on eye-tracking research and has resulted in more diverse applications (105). The first description was contributed by Wade and Tatler (106), where he used mirrors to observe the eye-movement of test objects and discovered that eye-movements are not smooth (107). Later, to gain more insights about eye movements, Delabbarre (108) simultaneously succeeded in inventing the first eye-trackers. Although, rich information in the education area, in particular reading techniques, was conducted by the first eye-tracker, this tool was judged to be invasive.

The first non-invasive eye-tracking device which was capable to use in photography in recording eye movements was introduced by Dodge and Cline (104). By developing technology Buswell (109), invented the first eye-tracking device that enabled researchers to produce two-dimensional scan path by recording the reflection of the light. With emergence of image processing techniques in the early 1970's, the first digital eye tracking device was introduced, which worked by scanning the image of the eye for limbus (110). Thus, the performance of eye-tracking improved with new devices that tracked the pupil in-stead of limbus, which eliminated problems encountered by tracking vertical eye movements. Furthermore, new methodologies improved the eye-tracking by introduction of bright-pupil tracking (111). As technologies improve over the years, eye-tracking devices were developed to provide higher precision records of observers' point of view. Also, the latest eye tracking has a technology for natural body and head movement. Current eye-tracking devices are more capable and enable observers to have natural head and body movements (107).

Application Areas of Eye-Tracking

Early eye tracking research in reading and education present the relationship between eye movement and cognitive purpose. This improvement made a solid background for the application of eye tracking in neuroscience, psychology, and behavioral research (107). Eye tracking research not only is applicable in interactive purpose but also could be diagnostic. Different areas of studies use eye tracking from the past decade such as human-computer interactive and availability research (99, 112), transportation (113), driving (114, 115), petrochemical control rooms (116) and medicine (117). Eye tracking is used in the above fields mainly related to analyzing user behavior, measuring cognitive ability, and diagnostic ability. Although, eye tracking has been used in various fields, it is still unexplored in hazard identification in the construction safety.

Heat Map

One technique for visualizing data from eye tracking is a heat map, which is the graphical showing of eye movements. Heat maps are easy to generate due to showing data graphically and in color scale based on temperature. Also, heat maps represent a picture of patterns, and aggregate a huge amount of data (118). Thus, heat maps are widely practical in web usability studies (119), (120). According to Bojko et al. (118), Buscher et al. (120), although heat maps makes understanding the data easy, they have limitation in data analysis They only present density-based representation and it seems there is a limitation of sequential order of eye movement. Thus, before using them, one should understand the different types of heat maps and limitations and the exact goal of using them.

Eye-Tracking Metrics

Many eye tracking metrics were used to evaluate human cognitive processes. Fixation which is stationary eye positions over minimum duration, and saccades, which are quick eye movements are the most common measured metrics in eye tracking studies. Table 1 shows the fixation-related and saccade- related metrics identified from the literature review.

Table **2- 1**: Summary of eye movement metrics.

Metrics	Description
Frist fixation on target time	When there is an area of interest, this measurement is useful. In this metric, the time (in millisecond) that each participant take to look at a specific area of interest while viewing a picture is measured (121).
Percent of gaze on each area of interest	All continuous fixation duration and relatively short saccades time between them shows gaze duration within an area of interest. The of gaze duration looking at the specific element shows possible important of that element (99).
Number of fixations for each area of interest	The importance of each elements can be recognized by the number of frequent fixation on the specific area (99)
Run count	This metrics shows the total number of runs, in a case that a run is two continuous fixations in the same area of interest in a particular scene (106).
Fixation-duration mean	This metric in eye-tracking studies is valuable, and it is related to the task difficulty and complexity. The higher amount shows that the participant needed more time to compete the task (122).
Number of fixation	Base on the previous research, the higher number of fixations shows the complex situation that reduce the efficiency in investigating for the favorable targets (123).
Saccade amplitudes	This metric is calculated by dividing the distance between continuous fixations by the number of saccades (124). In many studies, mostly in computer-interface and usability research, higher amount of saccade amplitudes shows well design interface with adequate cues that users can find the favorable target faster (124).
Number of saccades	More number of saccades show that participant put more time for investigating the favorable target (98). Also, computing number of fixation minus one, shows this measure. (124).
Saccade/f ratio	The higher amount of ratio shows that participant spent more time investigating and less time processing and understanding targets (123).

Model Accident

An accident is “an undesired and unplanned event (but not necessary unexpected) event that results in (at least) a specified level of loss” (125). The more general term of “event” was defined by ISO guide 73, which is “occurrence or change of a particular set of circumstances”, which could contain something not happening or consider as an “accident” or “incident (126). There is a different concept as a definition or synonyms to “accident”. According to US Department of Defense (DoD) that use Mishap as one of the synonyms of accident: “an unpleasant event or series of events resulting in death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment”. All the definitions shown are concerned with unwanted or unpleasant events resulting in some level of loss. To prevent accidents, it is necessary to understand the nature of the events leading to accidents.

Accident models play an important role in the prevention accident programs and the training of users. They are simplified representation of the accidents occurring in real life. Each accident model has its own characteristics as to the types of casual factors’ that it high-lights. The main goal of introducing an accident model is to present a shared understanding within the foundation of how and why accidents happen. Here we discussed some of the common accident models.

Energy Model is rooted in epidemiology. This model developed by Gibson in 1961, and he based his model on the fact that a transfer of energy in excess of body injury threshold causes injury to a person (127). This model argues that physics’ laws could explain the happening of an accident: it occurs after there is an excess amount of uncontrolled energy and consequences depend on the amount of energy (128). This model however, is not totally accepted by (129). They believed that the root nature of this model could not have a good foundation in identifying hazards in routine work. Also, according to Brière (128), the model fails to suggest the appropriate safety evaluation under different circumstance.

Bird' Domino Model was suggested in 1974 which viewed an accident as a last domino in the 'domino sequence' where an accident is the result of a sequence of events. The first domino falls the second one and the second one's fall leads to the fall of the third domino, etc. This model argues that workers will be safe on the first domino, for example, site management does not fall (128). On the other hand, Li and Sun. (130) believed that accidents are related to many factors and it is inappropriate to consider accident as the last event in the sequence. Also, this model did not define a clear relationship between personal and organizational factors. Domino sequence arise misunderstanding that personal factors and mental stress play the same role in accidents (128).

Heirrich et al.(131) model present that more than one-fifths of the accidents are due to an unsafe act which finally lead to an accident. He also argues that the degree of the injury is an issue of probability. However, Cooke et al. (132) suggest that the Henrich's model consider too much details on urgent condition and it fails to consider unsafe circumstance which also have systemic and organizational causes.

Potential Accident Subject Model which proposed by Leather (133) argue that both endogenic and exogamic factors could affect the potential accident subject's acts and they lead to accidents in Potential Accident Subject (PAS model). The PAS insists the relationship between different stakeholders on accidents, such as workers, managers in the construction companies or employees who work outside the construction companies. In this model, any person even who victim himself account as a "Potential Accident Subject". In addition, individual's attitudes and behaviors are impacted by rewards and punishment given by seniors. Some finishing rewards tasks may quickly reduce workers to take short cuts and ignore the possible source of risks (130).

Rasmussen’s Work Behavior Model in 1994 suggested that construction workers’ work is shaped by economic, functional, safety related objectives and constraints. This model suggests three zones: safe zone, hazards zone and loss of control zone. Managers mostly move along the cost direction and site workers looking for least effort direction. In this view, safety plans on site are design based on pushing workers toward safety zone, however the pressure that push workers toward the safe zone required a continuous effort. Rasmussen thus suggested that accident prevention should concentrate on error tolerant work systems development. Eun and Resnick’s (134) Human Information Processing (HIP) Model was developed in 2000 is another important model. Kjellén (135) worked on human and environment interaction based on operators. In this model, people are considered as an information processor who has an ability to make their own judgment toward environmental risk, hazard or deviations. Accident occurs when people could not control and handle information under hard condition. Accident analysis help to recognize and identify the safety risks on site.

Yet, this model has two major problems. First, the model only focused on ‘cold’ factors with regards on human cognitive process which does not follow real life situation well. Emotional factors such as thread affect individual’s problem solving ability and accident prevention in the real life. Second, internal information processes are not considered in this model. Because of two problems above, application of this model is limited to deep investigation with experts’ participations (130).

Literature Gap

The aforementioned studies show very low concentration on understanding of risk and hazard perception in the construction industry. Although there are many studies analyzing risk and risk assessment, there are very few on measuring construction workers risk perception and risk taking tendency based on their sociodemographic variables such as age, working experience, marital status, number and children, etc.

According to the literature, eye-tracking research has been used in many fields of study. Even though the key characteristics of eye tracking research (namely that eye tracking is the only direct measure of attention) provide great potential for measuring, understanding and improving construction workers' attention, eye tracking remains unexplored in the field of safety in construction industry. This study addresses this gap in knowledge and application of a widely-developed technology in construction safety practices.

The primary gap among the various studies related to human behavior is the lack of studies considering both visual attention and risk perception of the construction workers. Workers act based on their perceptions of risk at the jobsite, and their hazard identification is related to their visual attention. So, we can conclude that safety improvement in the construction industry is the most appreciated beneficial effect of enhancing both worker's risk perception and hazard identification ability. Therefore, systematic understanding of unsafe behavior has great potential to contribute to the reduction and prevention of injuries and fatalities in construction projects.

Chapter 3

Methodology

Research Framework and Methodology

To achieve this objective, the proposed study analyzes the relationship between risk perception (in terms of psychology), sociodemographic variables (such as age, gender, number of children, education, etc.), attention, and visual perception. The study is conducted through three-step experiment to evaluate and analyze the relationship between worker's safety attitudes/behavior and perception of risks and hazards. The three-step experiments include Questionnaire, Balloon-Analogue-Risk-Task (BART), and Eye tracking assessment. At the first step, the questionnaire is conducted to assess participants working experience, knowledge, and psychologically measure their safety attitude and risk perception. In the second step, BART test is conducted to measure risk-taking behavior. The last step measures the construction workers' visual attention using eye-tracking technology (Figure 3-1).

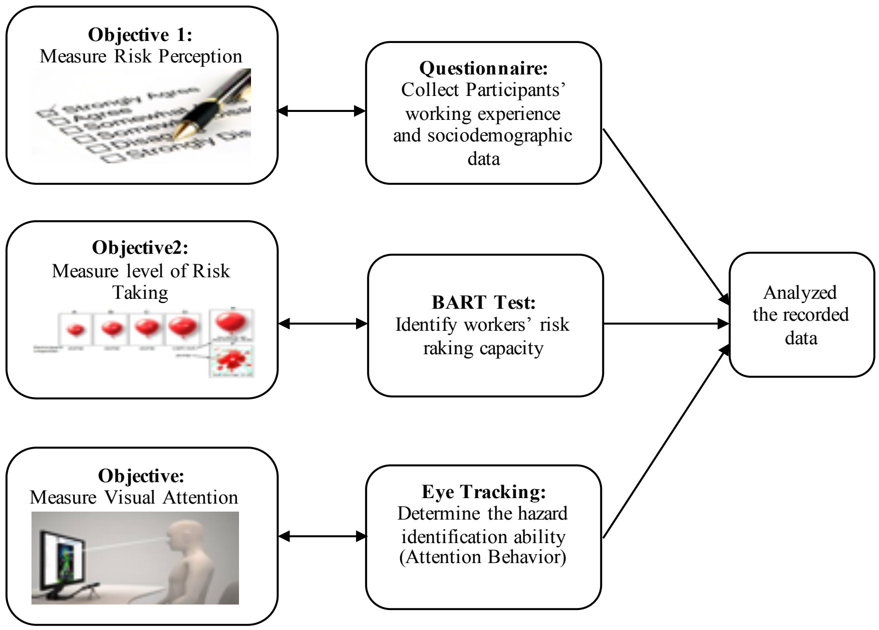


Figure **3- 1**: Research Framework.

Scope and Objective

The goal of this study is to investigate the role of human factors on hazard identification and risk perception of construction workers at the job site. To meet this goal, the following research objective regarding the source of human behavior should be answered:

- Understanding construction workers' risk perception.
- Understanding construction workers' hazard identification (visual attention).
- Understanding relationship between sociodemographic variables and construction workers' perception of risk, hazard and visual attention

The significance of this study is to apply psychology to address aforementioned objectives; accurately measure individual's tendency to take risk, identify their level of hazard identification; and ultimately identify ways to reduce worker's exposure to workplace hazards.

Research Hypothesis

In order to address the research objectives, the following hypothesizes were framed:

(1) Construction workers' sociodemographic variables such as age, experienced, number of children, safety training and etc. can help in understanding the perception of risk (psychology questioner and BART) and hazard identification (eye tracking).

(2) Construction workers who are taking greater risks (based on the results of the BART experiment) has less risk perception also, they would underestimate the level of danger. however, those who are less risky has higher risk perception and they would overestimate the level of danger.

(3) There is a positive relationship between higher risk perception and higher attention to hazards. Construction workers with higher visual attention, have higher risk perception.

Chapter 4

Assessment of construction workers' risk perception and risk taking capacity

This chapter addresses the objective 1 which is understanding construction workers' risk perception psychologically by conducting a questionnaire (step 1). Also, this chapter explain step 2 which address objective 2 (understanding construction workers' risk-taking capacity).

Objective

The main objective of the first step (questionnaire) is to assess risk and hazard perception among construction workers who have different sociodemographic variables and working experience (objective 1).

To address the main goals, the following objective should be addressed:

1) Identify sociodemographic characteristics of target population, and identify nine perceived risk variables and relationship among them based on the workers' responses,
2) Identify relationship between qualitative and quantitative hazard perception variables, and,
3) Investigate the relationship between socio-demographic variables and risk perception.

Methodology

Research design

This study conducted a psychological based survey and Balloon-Analogue-Risk-Task (BART) test to evaluate the risk and hazard perception of construction workers and measure their risk-taking behavior. The questionnaire is designed based on existing samples in literature in order to take into account personal and behavioral characteristics that could affect worker's safety (136), (137), (138), (139). Table 4-1 demonstrates each psychological variable as a single risk or hazard dimension (Q1, Q2 …, Q9). A preliminary pilot study was conducted and the language of the questionnaire is simplified and modified based on the participants' feedback.

Table **4- 1**: Qualitative variables (Risk Dimension)

Variables	Considered Factor	Question in survey (qualitative Dimension)
Q1	Workers' knowledge	Do you think you have enough knowledge about safety issues?
Q2	Awareness of safety and health officials	Do you think your company's safety officials are aware of the risk of your daily work?
Q3	Fear	How concerned are you about being hurt at work?
Q4	Personal vulnerability	What is the likelihood you might get hurt at work?
Q5	Seriousness of consequences	If a risk (hazard) situation occurs in your vicinity, how likely it is that you will get hurt?
Q6	Preventive action (fatality control)	Are you able to prevent a problem that could create a risk (hazard) situation?
Q7	Protective action (damage control)	In an eventual risk (hazard) situation, how likely you might intervene to control it?
Q8	Potential Catastrophe	Are risk (hazard) situations possible that involve a large number of individuals?
Q9	Delayed Consequences	Do you think your work can impair your health in the long run?

The questionnaire is divided into three parts. The first one is aimed at covering sociodemographic data and personal information such as worker's age, marital status, number of children, nationality, gender, education, trade of work and number of safety hour's trainings. According to Redmill and Rajan (46), two key approaches for risk assessment are qualitative and quantitative assessments. If we can measure the probability and consequence of a specific risk situation, the risk could be ordained in a numerical term. So, second part of the questionnaire contains nine questions related to the different qualitative variables of risk and hazard perception. A Likert-type scale is used to answer this part of the questionnaire. Participants' valued their perception of each dimension (i.e., Q1, Q2, …, Q9) between five answers which are scaled from one to five. In addition to nine qualitative dimension of risk perception, a single question for quantitative risk assessment is included. This question "How do you evaluate (from 1 to 10) the risk of having an accident or becoming seriously hurt at work?" provides a quantitative risk assessment as perceived by workers in their daily work. In addition to the quantitative and qualitative evaluation of risk perception through questionnaire, the third part asks about workers' point of view through factors influencing safety performance.

Participants

Construction workers and managers from different construction companies were asked to participate in this study and fill out the questionnaire. In addition to the workers, undergraduate and graduate students were recruited from the Architectural Engineering (Construction option) department at Penn State to participant in the study. All the participants had experience in construction projects. The results were analyzed using 126 data samples collected (104 male and

22 female). Table 4-2 summarizes the descriptive statistics of the subject pool and the safety questionnaire results.

Table **4- 2**: Summary of the Experimental Design

	N	Mean/Percentage	Std. Deviation
Age		33.47	12.92
Gender - male	104	82%	N/A
Gender - female	22	18%	N/A
Work experience	-	10.91 yr.	11.93 yr.

Balloon-Analogue-Risk-Task (BART) test

In the second step, the BART test was carried out on the subsample (N=38) of the original population to further investigate the risk-taking tendency (research objective 2).

First, participants are asked to pump up a computerized balloon. The maximum number of pumps that can be made to a balloon is 128, and for each pump, the participant is awarded a small amount of money that is placed in a temporary bank (5c per pump). The participant can pump the balloon 1 to 126 times, and must decide when to stop pumping. If they stop pumping before the balloon bursts, the money in the temporary bank is placed in a permanent bank. However, if the balloon bursts before they stop pumping, the money in the temporary bank disappears. Thus, people who are willing to pump up the balloon more are essentially taking greater risks, whereas people who quit early can be viewed as being more cautious and less risky. Lejuez et al. (2002) has shown that one’s propensity to pump up the balloon is positively correlated with real-world risk behaviors.

Statistical analysis

Data was analyzed using R statistical computing software. The first step in our data analysis was to describe the characteristic of the target population using descriptive statistics. Next, the descriptive statistics such as average and standard deviation were computed for each qualitative risk perception variables in the questionnaire. After establishing the profile of answers to the nine qualitative dimensions in the survey, the correlation between the perceived risk variables were studied using correlation plot to determine the possible relationship between these variables. Next the five effective factors identified by the subjects as significant in safety such as economic, human, environmental, organizational factors and safety training, were studied for different trades and professions in construction industry. In addition, multiple linear regressions analysis was performed to identify the significant perceived risk variables in determination of quantitative risk perception.

To further investigate the role of socio-demographic information collected on the perceived risk score by the survey takers, t-distributed stochastic embedding (t-SNE) (cite t-SNE) algorithm was used. This algorithm reduces the dimensionality of the perceived risk score from 9 to 2 in a way that similar object is modeled by nearby point and dissimilar object are modeled by distant points which enables us to visually examine the distribution of the answers to survey questions. Next, the results of dimensionality reduction were used to cluster the answer to two dissimilar groups, and the socio-demographics of each group were further investigated to determine differentiating attributes of the workers clustered in each group.

In addition, to better understand the relationship between the sociodemographic information obtained from participants and their quantitative risk assessment, a regression analysis was performed. Also, the 5 significant factors in construction safety rated by participant from less to most significant were further investigated for each construction trade to understand the disparities between workers in different trades of construction.

Finally, in order to study relationship between workers ‘risk perception and their risk-taking tendency (based on BART results), the average number of pumps per experiment which is an indicator of risk taking tendency in the two clusters was determined.

Results and Discussion

Descriptive statistics of perceived risk

To meet the first objective (identifying sociodemographic characteristics of target population, and identifying nine perceived risk variables), it is important to establish the basic descriptive information about the sociodemographic characteristics of target population of this study. Table 4-2 showed that, the average age of surveyed worker is (33.47 ± 12.92) and, the surveyed worker has on average (10.91 ± 11.93) years of work experience. The descriptive statistics, mean and standard deviation of perceived risk for each qualitative variable is provided in Table 4-3. As it can be seen, the results fluctuate between Q4 which is personal vulnerability (Average 2.44) and Q2 which is the knowledge of safety officials (average 4.33).

Table **4- 3**: Mean and standard deviation for the analyzed sample

	Q1*	Q2*	Q3*	Q4*	Q5*	Q6*	Q7*	Q8*	Q9*
Average	3.81	4.37	2.68	2.44	2.67	3.99	4.02	2.89	2.90
Standard Deviation	0.85	0.85	1.44	0.90	0.84	0.95	0.91	1.12	1.12

* Q1= Workers' knowledge, Q2= Awareness of safety and health officials, Q3= Fear, Q4= Personal vulnerability, Q5= Seriousness of consequences, Q6= Preventive action (fatality control), Q7= Protective action (damage control), Q8= Potential Catastrophe, Q9= Delayed Consequences.

Figures 4-1 and 4-2 show the mean and standard deviation of score for each qualitative variable and illustrate the perceived risk profile from the construction workers view. It can be seen that variables Q2 (awareness of safety and health officials), Q6 (fatality control) and Q7 (damage control) have the highest mean scores with relatively low variation in the data. Variable Q3 (fear) shows the highest standard deviation.

According to figure 4-1, the means of most of variables are more than neutral, which shows the workers are concerned at work and they believe that they might get hurt at work. This could confirm that the construction workers positively perceive risks and hazards at the job site.

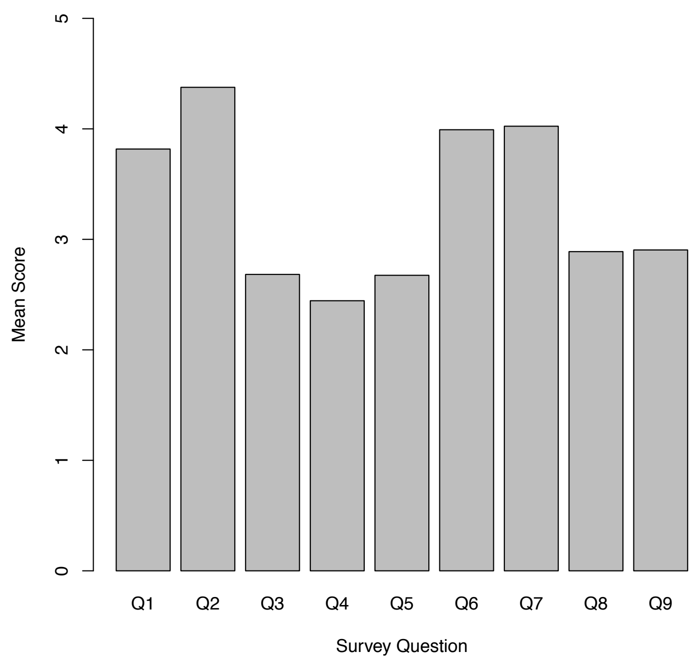


Figure **4- 1**: Mean Score for qualitative risk variables

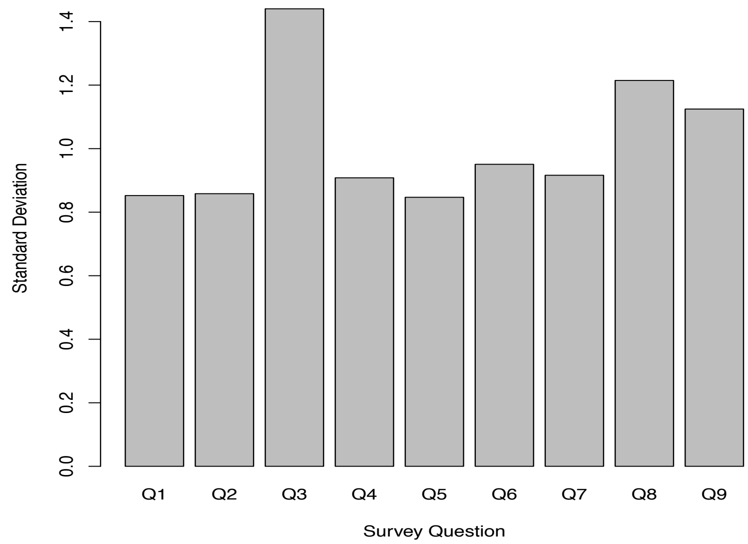


Figure **4- 2**: Standard Deviation for qualitative risk variables

Correlation among perceived risk variables

To continue addressing the first objective which is identifying nine perceived risk variables and relationship among them based on the workers' responses, the correlation plot is presented (Figure 4-3).

Correlation plot is the visual presentation of matrix of Spearman's rho correlation coefficients between each variable and the corresponding P-values with 95% significates level reported in Figure 4-3. The off diagonal values vary between -1 and 1 and the diagonal term are equal to 1 which is the correlation of the random variable with itself.

Figure 4-3 shows that the variables Q6 (preventive action) and Q7(protective action), Q4 (personal vulnerability) and Q3 (fear), Q5(seriousness of consequences) and Q4(personal vulnerability), and Q1(workers' knowledge and Q2(awareness of safety and health officials) have the highest positive correlation among paired variables. Furthermore, significant correlation exists between variablesQ7(protective action) and Q3(fear), Q8 (potential Catastrophe) and Q3(fear), Q8 (potential catastrophe) and Q4(personal vulnerability) and, Q3(fear) and Q1(workers' knowledge). The highly-correlated variables require additional attention during the regression analysis which is discussed in the next section.

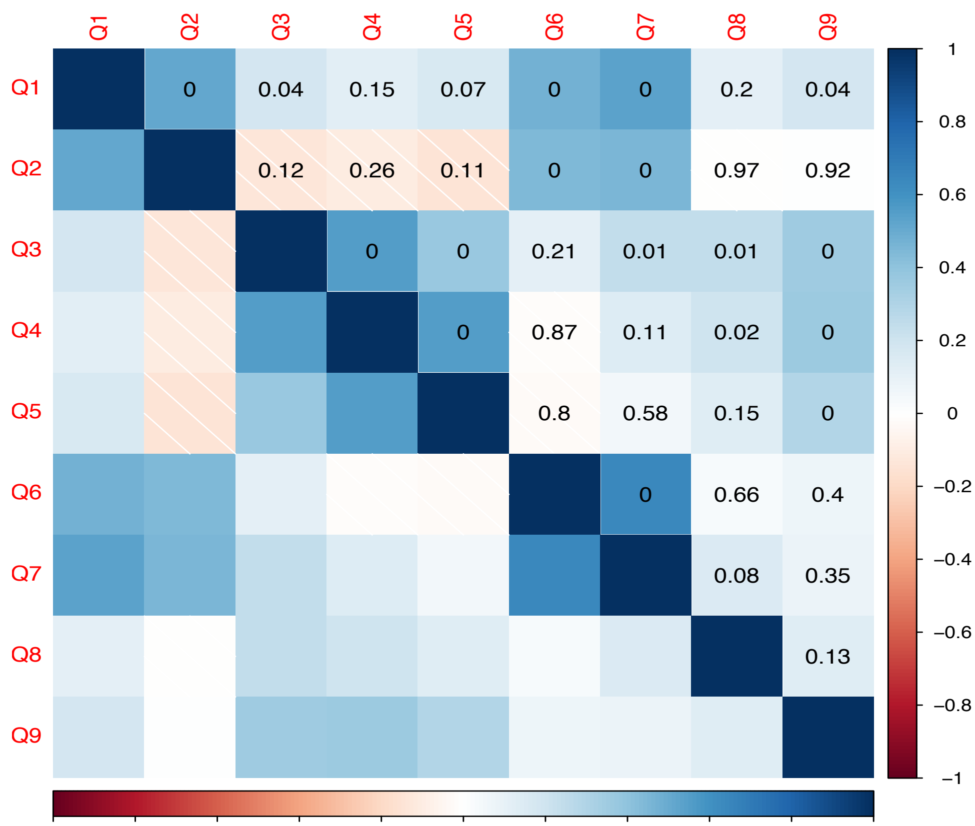


Figure **4- 3**: Correlation Plot between perceived risk variables.
Q1= Workers' knowledge, Q2= Awareness of safety and health officials, Q3= Fear, Q4= Personal vulnerability, Q5= Seriousness of consequences, Q6= Preventive action (fatality control), Q7= Protective action (damage control), Q8= Potential Catastrophe, Q9= Delayed Consequences.

As mentioned, in order to understand the relationship among each of the nine variables, the correlation plot is presented (Figure 4-3). The results demonstrated that the two variables Q6 and Q7 which shows the preventative actions and protective actions respectively, have a positive correlation. This indicates that construction workers who believed hazardous situation can have serious consequences on their health also believed that they cannot prevent a problem that could create risks or hazardous situation. Also, correlation between variable Q1(workers' knowledge) and Q2(awareness of safety and health officials) shows that workers who are confident to their safety knowledge also are confident about their company's safety knowledge.

In addition, variable Q3 (workers' fear) and variable Q4 (workers' personal vulnerability) showed a positive correlation. Due to positive correlation, the score selected in variable Q4 increases when higher scores are given to variable Q3 and consequently construction workers who are more concerned about getting hurt at work perceive more personal vulnerabilities. Correlation between two variables Q5 (seriousness of consequences) and Q4 (seriousness and consequences of hazards and personal vulnerability), have a positive correlation. This indicates that construction workers who believed they might get hurt at work, also believed hazardous situation can have serious consequences on their health.

Relationship between perceived qualitative risk variable and quantitative perceived risk

To further study the relationship between perceived risk factors and the global risk factors (objective 2), a stepwise multilinear regression was performed, in which global risk factor was taken as dependent variable and the 9-perceived risk factor as independent variables. The stepwise regression was performed in both direction by evaluating Akaike information criterion (AIC) number and selecting combination of variable that minimizes information loss. The model removed the variables Q2, Q3, and Q7. The regression results and coefficients is presented in Table 4-4. The adjusted R-squared value for the stepwise regression was 32.1%.

Table **4- 4**: Stepwise regression coefficient

Coefficients	Estimate	t value	P-value
Intercept	-0.6900	-0.584	0.5603
Q1	-0.4997	-1.967	0.0517
Q4	1.3919	5.369	7.98e-08
Q5	-0.4108	-1.504	0.1353
Q6	0.5019	2.184	0.0311
Q8	0.2789	1.747	0.0842
Q9	0.3039	1.621	0.1079
F-test	F-value	3.26 (on 10 and 118 degrees of freedom)	
	P-value	0.00094	
AIC	165.7		

The linear regression between that perceived risk factors (Q1-Q9) and the quantitative dimensions related to risk perception shows that variables Q1 (worker's knowledge), Q2 (Knowledge of safety officials), Q4 (personal vulnerability), Q5 (seriousness of consequences), Q6 (preventive action), Q8 (potential catastrophe) and Q9 (delayed Consequences) can explain 32.1% variability in quantitative dimension related to risk perception. In other word, Q1, Q2, Q4, Q5, Q6, Q8, and Q9 predicts 32.1% of the risk perceived, generally by construction workers. Since all the variables have the same scale and units, the magnitude and sign of the coefficients can be interpreted as the increase/decrease in response (quantitative perceived risk) due to unit increase/decrease in specific predictor while others are fixed. The regression coefficient for variable Q4 is the largest coefficient (1.3919) and has a very small P-value close to 0. Therefore, the workers risk perception increases with increasing personal vulnerability.

Dimensionality reduction and clustering

In order to visually examine the distribution of the answers given to 9 risk qualitative dimensions, and to meet the third objective (investigating the relationship between socio-demographic variables and risk perception), the dimensionality reduction technique was used to reduce the number of dimensions of the question space to 2 (Figure 4-4). t-distributed Stochastic Neighbor Embedding (t-SNE) (140) is a nonlinear dimensionality reduction technique that seeks to preserve the local structure of the data. In addition, by visual inspection of Figure 4-4, it is evident that the t-SNE reduced data can be clustered in 2 separate clusters. The clustering was performed using the k-means clustering algorithm (141) based on Euclidian distance between each point. Each color in Figure 4-5 represent a separate cluster. Studying the sociodemographic information collected from participants and their response to the questionnaire enable us to identify similarities and significant differences between the two clusters. Figure 4-6 shows the average score given by workers in each cluster to the 9 risk qualitative dimensions. It can be seen that workers in cluster 1 have 5 questions with below neutral score while workers in cluster 2 have only two question scored below neutral value. This shows that workers in group 2 have perceive higher risk.

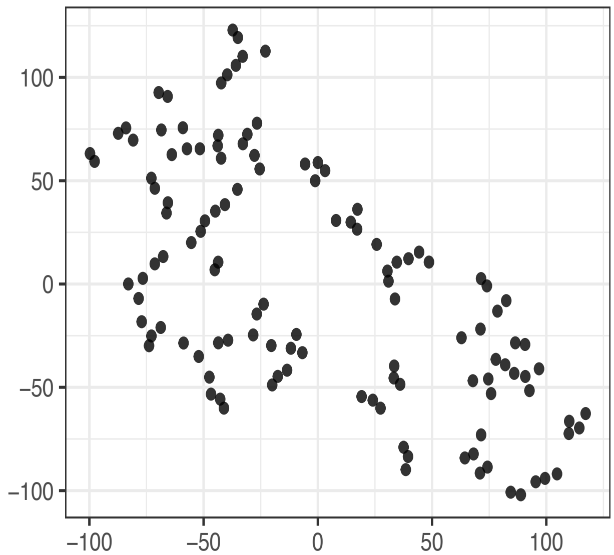


Figure **4- 4**: t-SNE visualization

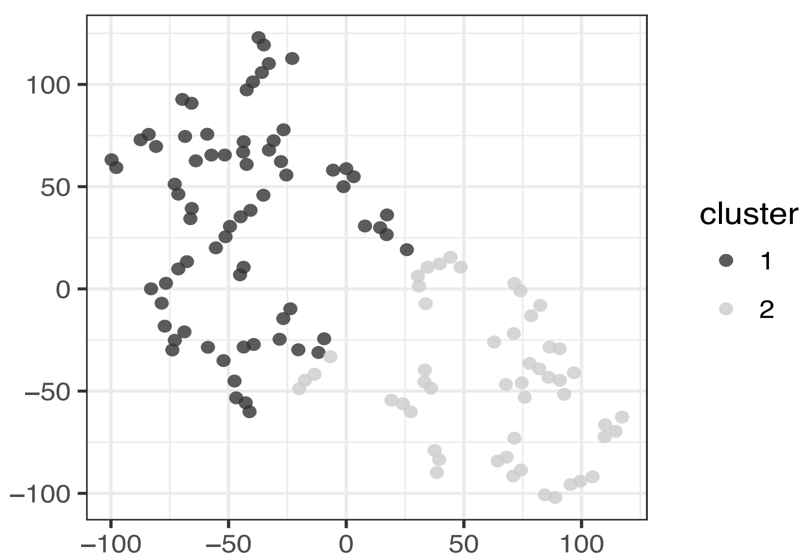


Figure **4- 5:**K-means clustering algorithm

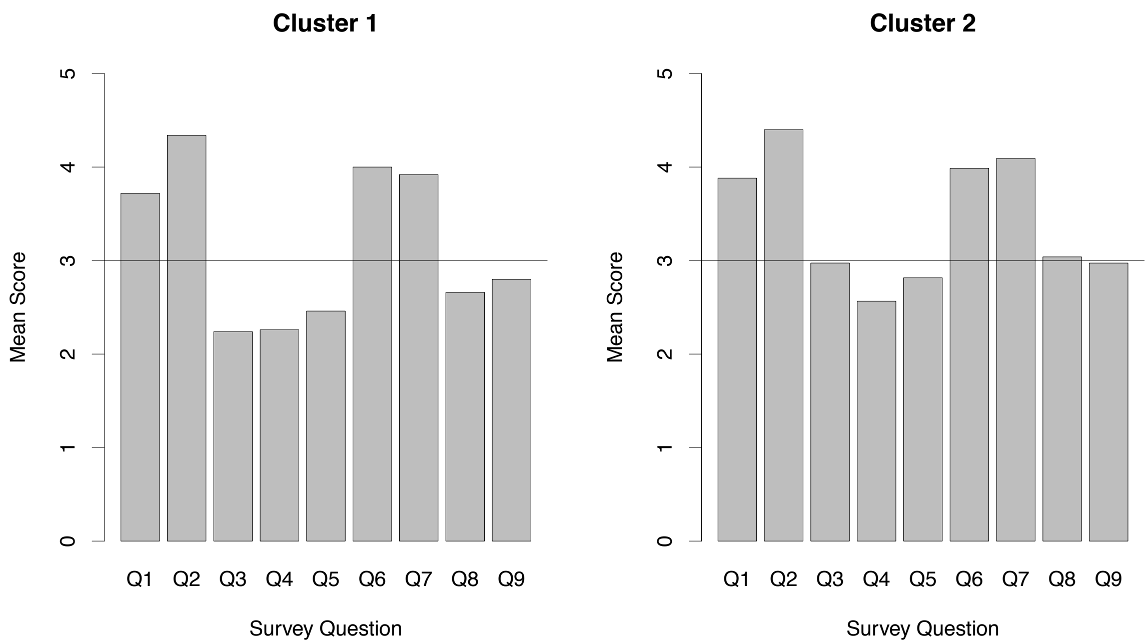


Figure **4- 6**: Mean Score for Cluster 1 and Cluster 2

Sociodemographic factors

To further investigate the sociodemographic attributes of workers in each cluster, the worker's years of experience in their trade where investigated. Figure 4-7 show the histogram of workers experience for the two clusters obtained from previous section. The workers in cluster 2, have on average 4 more years of work experience compared to workers in cluster 1. Another related sociodemographic variable that represents a structural difference between the two clusters is the number of children each worker has (Figure 4-8).

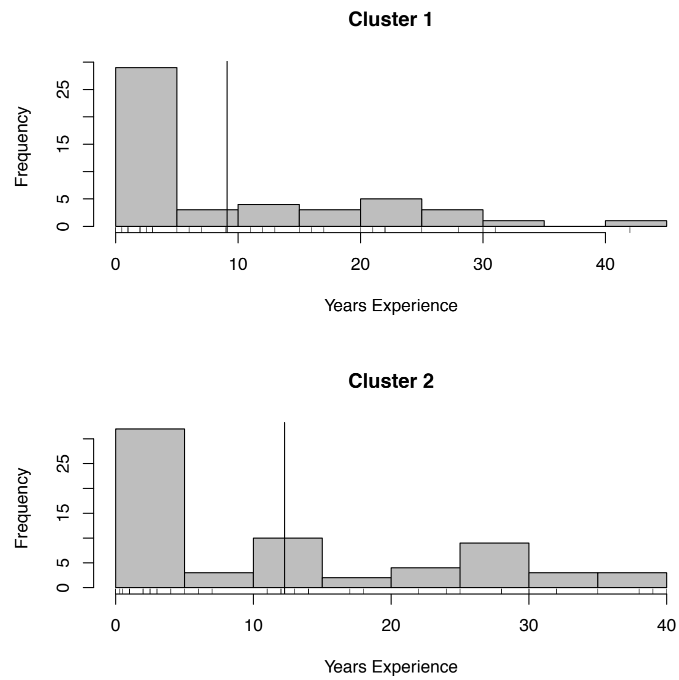


Figure **4- 7**: Distribution of workers experience in two clusters.

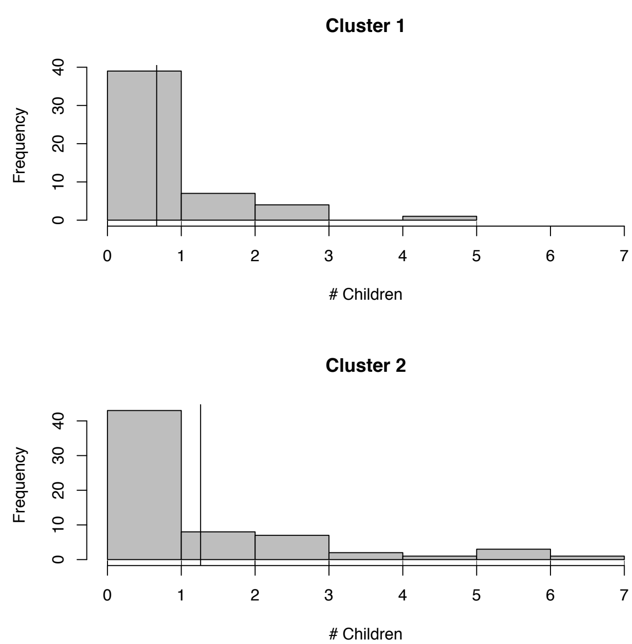


Figure **4- 8**: Distribution of workers age in two clusters.

Regression between quantitative risk variable and sociodemographic factors

To further investigate the effect of socio demographic attributes of the workers in their risk behavior, a regression analysis was performed between the socio demographic variables and the quantified risk perception. In addition, the interaction between these variables and only significant interaction terms remained in the model to improve the readability and inference.

Table **4- 5**: Regression model between perceived quantitative risk and socio demographic variables.

Coefficients:	Estimate	Std. Error	T-value	Pr (>|t|)
(Intercept)	6.927	2.515	2.754	0.0081
Marital Status: Married	39.971	12.202	3.276	0.004
Marital Status: Single	26.854	10.065	2.668	0.016
Number of Children	3.617	1.611	2.245	0.038
Trade: Demolition	34.427	11.072	3.109	0.006
Trade: Equipment Operator	14.254	3.856	3.696	0.002
Trade: Masonry	23.101	8.408	2.747	0.013
Trade: Plumbing	8.206	3.807	2.156	0.045
Gender: Male- Number of Children	-9.058	3.701	-2.448	0.025
Gender: Male- Trade: Construction management	-12.279	3.925	-3.128	0.006
Marita Status: Male- Number of Children	-27.384	8.575	-3.193	0.005
Marital Status: Male – Trade: Construction management	-18.86	4.913	-3.839	0.001
Marital Status: Male- Trade: Masonry	-10.412	4.537	-2.295	0.034
Marital Status: Male- Trade: Other	-0.059	0.025	-2.356	0.030
Marital Status: Male- Trade: Structural Engineer	-2.293	1.083	-2.117	0.048
Number of Children- Years of Working	-14.867	5.159	-2.882	0.010

Number of Children- Trade: Construction management	5.417	2.103	2.576	0.019
Number of Children- Trade: Demolition	0.618	0.189	3.275	0.004
Number of Children- Trade: Painter	0.734	0.219	3.350	0.004
Years of Working- Trade: Construction Management	0.016	0.006	2.921	0.009
Years of Working-Trade: Electrical	-0.814	0.245	-3.319	0.004
Years of Working- OSHA Training hours	0.539	0.206	2.624	0.017
r^2: 089		f-statistic (p-value): 0.007		

The variables shown in Table 5 can explain 0.89% of variation in quantitative risk variables. As can be seen from reported regression coefficients, number of children, marital status and trades' type (such as equipment operator and demolition) have positive and significant coefficients and the quantitative risk increases with increasing the value of the mentioned variables. Also, interaction terms between several have noticeable effect on response variable, namely, the interaction term between OSHA Training have significant but opposite relation to quantitative risk variable

Effective factors influencing safety across different construction trades

It is illuminating to further investigate the 5 effective factors identified as significant in worker's safety and rated by the participants from 1 to 5 (1 indicates the most significant) Table 4-6 show the mode of scores given by the participant across all trades.

Table **4- 6**: Important safety factors and number of accident reported per trade

Trade	Human Factor	Economical Factor	Safety Training	Environmental Factor	Organization Significance	Number of Accident
Carpenter	1	3	4	5	2	5
Construction Management	1	2	3	5	4	11

Demolition	1	4	2	5	3	0
Electrical	1	4	3	2	5	19
Equipment Operator	1	5	3	2	4	2
General Contractor	1	5	2	4	3	0
Health and Safety	1	5	2	4	3	2
Laborer	1	5	2	4	3	8
Masonry	2	5	1	4	3	1
Mechanical	1	5	3	2	4	1
Other	1	5	2	4	3	14
Painter	4	5	1	2	3	0
Plumbing	1	5	4	3	2	1
Superintendent	1	3	2	4	3	2

It can be seen that participant in 12 out of 14 reported trades chosen human factor as the most important factor influencing safety. Only masons and painters chose other factors as most significant. The masons and painters have chosen safety training as most significant factors. Another important observation is that electrical workers and construction managers have the highest number of accidents.

Relationship between risk taking tendency (BART results) and risk perception

As mentioned, the second step was conducting BART test to identify risk takers (answer to research objective 2). First, we identify the relationship between worker's risk taking capacity (results from BART) and workers' risk perception. The hypothesis is that the participants who have higher tendency to take greater risk (higher average pumps) has more risk perception based on qualitative and quantitative risk perception assessment in questionnaire.

Workers' risk perception was investigated based on their response to the nine qualitative variables in the context of two clusters previously. Figure 4-9 shows the average number of pumps per experiment which is an indicator of risk taking tendency in the two clusters.

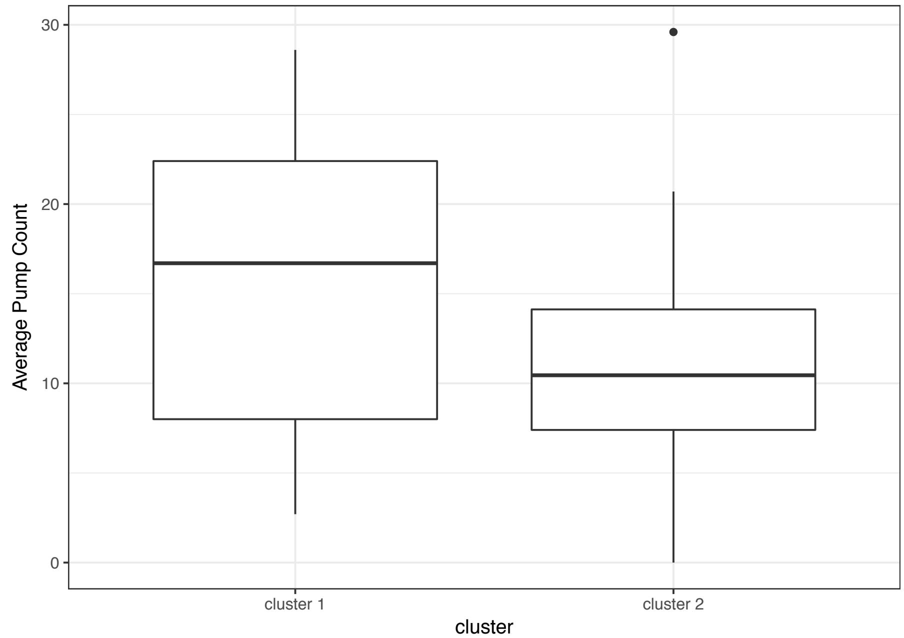


Figure **4- 9**: Distribution of average pump count in each cluster

It can be seen that, the median pumps count in the cluster associated with higher risk perception (Cluster 2) is lower than the cluster associated with lower risk perception. Figure 4-6 indicated workers in cluster 1 who have 5 questions with below neutral score have more risk perception while workers in cluster 2 members have only 1 question scored below neutral value. Also, Figure 4-6 showed that workers in cluster 2, have on average 4 more years of work experience compared to workers in cluster 1. Cluster 2 also have more children (Figure 4-8). Consequently, experienced workers with more children has the higher risk perception and less risk-taking tendency, while workers with less working experience and fewer children, has lower risk perception and more tendency to take a risk.

Conclusion

This chapter address the objective 1(understanding construction workers' risk perception psychologically) by conducting a questionnaire and objective 2 (understanding construction workers' risk-taking capacity) with BART test.

Based on the obtained results, it was found that:

- Construction workers' risk perception is high. In other words, they regard their work as risky.
- By investigating the relationships between sociodemographic variables and quantitative and qualitative risk perception, we have concluded that sociodemographic information can be used to understand the workers' risk perception.
- Workers with more working experience and more children perceives risk more than less experienced workers. Also, BART test suggests that experienced workers' who also have more children are less risky than others.

Chapter 5

Assessment of Construction Workers' Visual Attention

After understanding construction workers' risk perception (step 1) and risk taking tendency (step 2), in the third step, we determined the construction workers' hazard identification ability and visual attention. This chapter address the objective 3 which is understanding construction workers' hazard identification ability (visual attention) using the eye tracking technology.

Objective

The objective of the third step is to understand construction workers' visual attention and hazard identification using the eye tracking technology (objective 3) and investigate the relationship between sociodemographic variables and construction workers' perception of risk, hazard and visual attention

To achieve this objective, the present study:

(1) Investigates how participants scan a picture to identify hazards (using heat maps and eye movement metrics).

(2) Understands relationship between participant's eye movement metrics (eye tracking results) and hazard identification score (based on interviewing participants).

(3) Understands the relationship between construction worker's visual attention and risk perception based on the sociodemographic data

Methodology

In the third step of the study, the OSHA safety training photos displayed on the monitor and the participants were asked to take a look at the photos for a certain period of time while their eye movement was measured. Participants were informed that construction photos may contain a hazardous situation, and the eye tracking records their eye movement and fixation time. The photos range from near misses to the unsafe behaviors/conditions with high potential for accidents.

After participants looked at the photos in the monitor, we interviewed participants. They were asked to identify the actual or potential hazards they see for each photo that we showed them with eye tracking (hazard identification score) to compare them with eye tracking data. Along with identifying potential hazards, the participants were asked to rate the level of danger (or level of hazard) presents in the safety photo (severity score). Construction safety professionals participating in this study were asked to determine the severity level of the hazards in each photo. This severity level is used as the baseline to test the hypothesis. The hypothesis is that participants who has more risk perception (based on the questioner) and taking less risks (based on BART results) are expected to overestimate the level of danger, while the participants who are taking greater risks and has lower risk perception are expected to underestimate the level of danger present in the safety photos.

Four different levels of severity including Catastrophic, Major, Moderate, and Minor were defined. The following equation was used to calculate the severity score.

$$\text{Severity Score} = \sum_{i=1}^{10}(\text{Correct Answer} - \text{Subject's Answer})_i$$

where, Catastrophic = +4, Major = +3, Moderate = +2, and Minor = +1.

For example, if the correct answer is Major and the subject picked Minor, his/her score will be +3 – 1 = +2, which means that the hazard is underestimated and if the subject picked Catastrophic, his/her score will be +3 – 4 = -1, which means that the hazard is overestimated.

It should be noted that the eye movement data and participants' responses are used in this study to quantify both visual attention and measure participants' perception of hazard. Therefore, it is possible to learn precisely "where participants look" and "what they look for".

Experimental Design

In this study Tobii X2-30 compact eye-tracker is used to record eye movement data (figure 5-1). The technical specification of the eye-tracker includes: gaze accuracy of 0.4 to 0.5-degree range, precision of 0.32 to 0.45 degrees, data rate 30 Hz, freedom of head movement 50 (width) 36 (height) × 90 (depth) cm, calibration 9 points (~ 15 seconds to complete), monocular and binocular tracking capability.

Figure 5- 1: Tobii X2-30 compact eye-tracker

In this experiment, every single participant was subject to every single safety photo. Since the focus of this study is on construction safety, all participants for this experiment are drawn from construction workers or people who had worked in construction jobsites. In this step, eye tracking test was carried out on the subsample (N=38) of the original population and all the participants had experience in construction projects. The data was collected from 31 males and 7 females. Table 5-1 summarizes the descriptive statistics of the subject pool and the safety questionnaire results. As it can be seen in this table, the average age of surveyed worker is (36.94 ± 12.12) and, the surveyed worker has on average (13.34 ± 12.61) years of work experience.

Table **5- 1**: Summary of the Experimental Design

	N	**Mean/Percent**	**Std. Deviation**
Age		36.94	12.12
Gender - male		81.9%	N/A
Gender - female		18.4%	N/A
Work experience		13.34 yr.	12.61 yr.

In total, ten safety photos were created and shown to the participants. All photos were taken into consideration for the correlation analysis. Each participant spent 10 seconds viewing the photos. Figure (5-2) shows one of the participants replay eye tracking experiment viewing (fixation behavior). Eye tracking test is designed to examine participants' viewing behavior and attention distributions when shown a hazardous situation in a construction site. The experiment measures participants' cognitive processing to determine whether or not a hazard is present in a given situation.

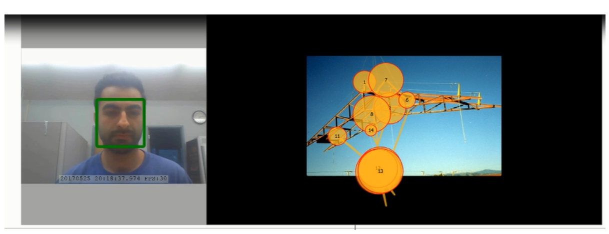
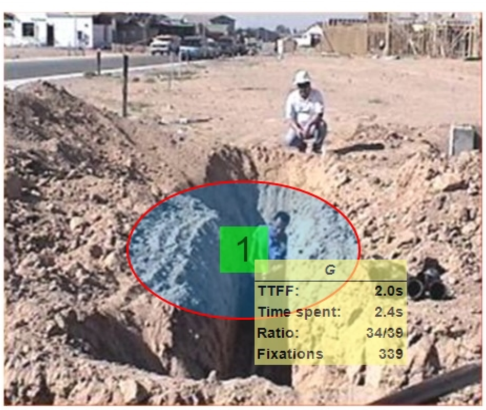


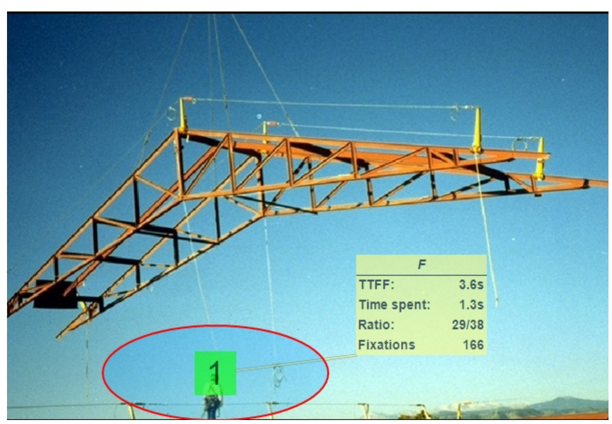
Figure 5- 2: eye tracking replay experiment test.

Area of Interest

After collecting the eye tracking data, the first step of analyzing the relationship between eye movement parameters and behavioral parameters (e.g. fixation) is to define the areas of interest (AOI) in each photo. AOI(s) are relevant areas of the stimulus and are closely connected to the research question and the corresponding research design. For example, in marketing-related studies, total time that each observer views the desired target (brand area) on a home page is important for specialist. In this study, the AOI is defined to find out how participant scan a picture in order to identify hazards. Several photos containing construction safety hazard are selected and their AOI are defined. To ensure consistency in obtained results, the AOI is defined as 3% of the total area. The construction safety professionals participating in this study identified the areas in each picture, and two examples are shown in Figure 5-3. As it can be seen in these figures, the Time Spent in AOI (second) which is defined based on total duration of all respondents' fixation is shown.



(I)



(II)

Figure **5- 3**: Picture I and II's Areas of interest.

Results and Discussion

The experiment was conducted on 38 participants and data was collected according to the established protocol. The iMotion 6.1 software (human behavior research, simplified software) was used to extract data and perform the analysis. (Figure 5-4).

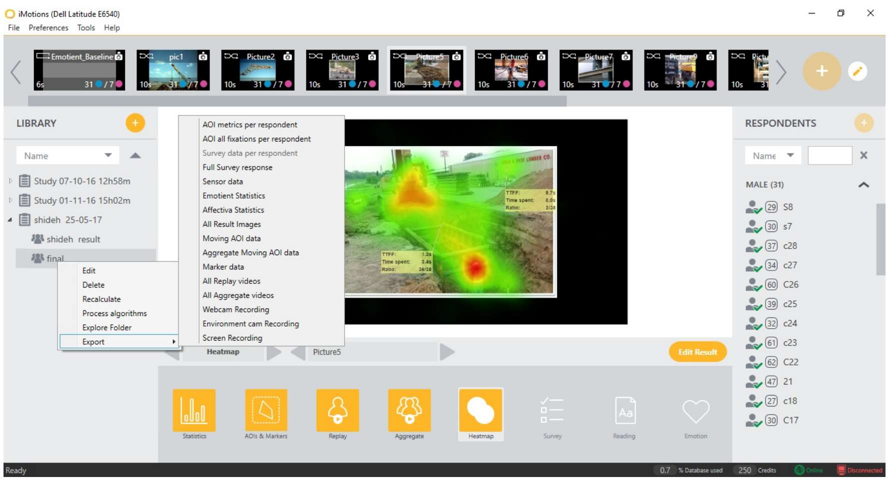


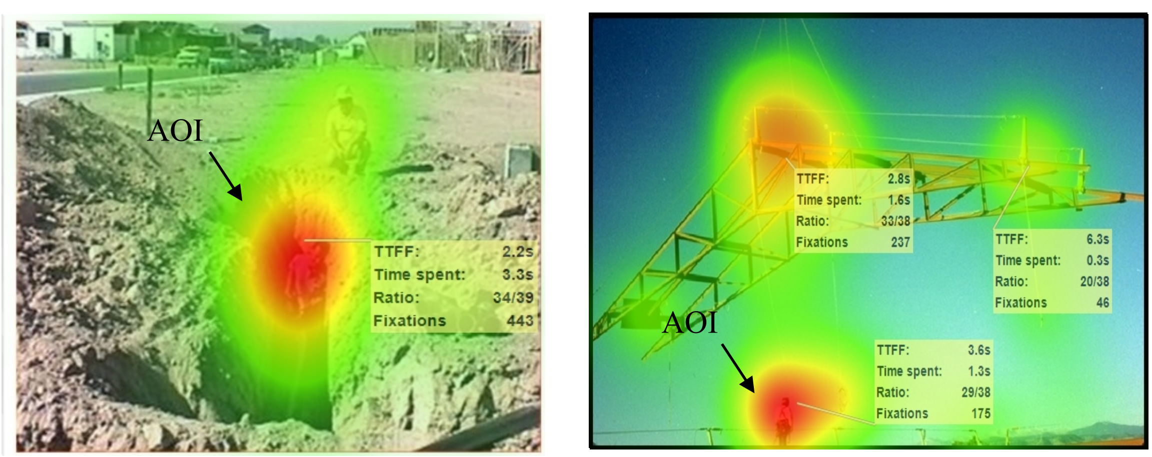
Figure **5- 4**: iMotion software to export eye tracking data.

In order to address objective 1 (investigates how participants scan a picture to identify hazards) the heat map was used to compare visual attention of participants' eye movement with their hazard identification abilities. Then, the eye movement metrics are analyzed to understand how fast participants could identify the hazardous situation (area of interest) in photos and

how area of interest captured their attention, and how the participants searched and scanned pictures. In order to address objective 2, which is understanding relationship between participant's eye movement metrics (eye tracking results) and hazard identification ability (based on interviewing them), the correlation analysis is created between the fixation duration and hazard identification score. In order to address objective 3 (i.e., understanding the relationship between construction worker's visual attention and risk perception based on sociodemographic data), the eye movement metrics are studied in two clusters obtained in previous section based on the qualitative risk behavior of participants. This has been done after examining the relationship between hazard identification scores and fixation duration.

Heat maps and Hazard identification

Heat map shows the areas with a large amount of interest and the aggregated eye fixation of those areas which is shown in red. The absolute duration heat maps are created by combining data from all of the participants to provide a quick view of average existing viewing patterns. To present the potential application of eye tracking technology for measuring construction worker’s attention, a heat map for two photos is shown in Figure 5-5. Heat maps clearly show which objects capture participants’ attention in an area. Although, the absolute duration heat map demonstrates the average viewing pattern, the heat maps created per each participant for each image present individual visual attention.



(I) (II)

Figure 5- **5**: Heat maps for photo I and photo II

To further investigate objective 1 (investigates how participants scan a picture to identify hazards), Figure 5-5 indicates the Time Spent in AOI (I) which is defined based on total duration of all respondent's fixations. The red area shows higher duration in compare with green area. For example, in Figure 5-5, the Time Spent in AOI in picture I is 3.3s while in picture II is 1.3s. This shows that AOI in picture I captured most of the participants' attention. However, as it can be seen in picture II, participants also pay attention to other AOIs based on the time they spent which is 1.6 and 0.3 second.

Eye Tracking Metrics

One of the important steps in eye tracking data analysis is to compare visual representation of participants' eye movement with their hazard identification abilities. So, heat maps are created to compare the number of hazards identified by each participant. After that, eye movement metrics are analyzed. Eye movements showed which AOI(s) is identified faster, which areas of interest are perceived more important, and how participants pay attention and scan images. The following questions are answered based on the eye tracking metrics:

1. How long will take a participant to see the AOI for the first time? (Time to the first fixation on target)
2. How long will a participant fixate on an AOI on average? Gaze %(time) on each target
3. In a given time, how many times will a participant fixate on an AOI? (Number of fixation per AOI)

The two-dimension eye movement analysis is based on calculating the visual angle of pairs (or more) of data points in the distance between successive data points (x_{i+1}, yi_{+1}) and a time series (x_i, y_i) . Based on this concept, the following eye tracking metrics are measured for all AOI(s) in each image: the time to the first fixation on an AOI; the average proportion of gaze duration on each AOI based on time; the average number of fixations per AOI and the average run count. The results of the two photos (out of ten photos) are shown in Table 5-2.

Table 5- 2: Mean value of eye tracking variables per area of interest

Pictures	Time to the first fixation on target (ms)	Gaze %(time) on each target (ms)	Number of fixation per AOI_Avg
I	2295.368	31.28	6.50
II	357.579	22.42	4.39

As it can have been in Table 5-2-picture I, the time of the first fixation in the AOI shows the unsafe access to enter and exit, which is a hazardous situation captured participant's attention quicker than other areas of photo. This is an important finding since based on the previous studies a lower first fixation time shows that target more captured people's attention (142). Also, the results of the analysis indicate that participants spent more time on the AOI (larger gaze proportion, number of fixations). The highest proportion of gaze duration looking at the AOI shows the importance of the existing hazardous situation in each photo to participants.

In picture II, the AOI was a worker who is standing under the steel truss structure and received 22.42% of the proportion of gaze duration. This means that, on average, participants paid less attention to the area of interest in picture 1 which is 31.28%. They looked at the other part of the photos to find the hazard and didn't focus their attention as long as the actual hazard. Also, the first fixation time for AOI is higher than photo I, which shows finding this hazard was not as quick as the hazard in photo I.

Hazard identification and fixation time

One hypothesis is that there is a relationship between participants' ability to correctly identify the hazard in stimuli and visual attention metrics obtained from eye tracking experiment.

To this end, the distribution of the participant fixation duration and time to first fixation (i.e., the time from beginning of the experiment to first fixation on the AOI) is compared when they correctly and incorrectly identified the hazard. Figure 5-6 show the Tukey box plot, indicating the distribution of the fixation time for the two mentioned situations.

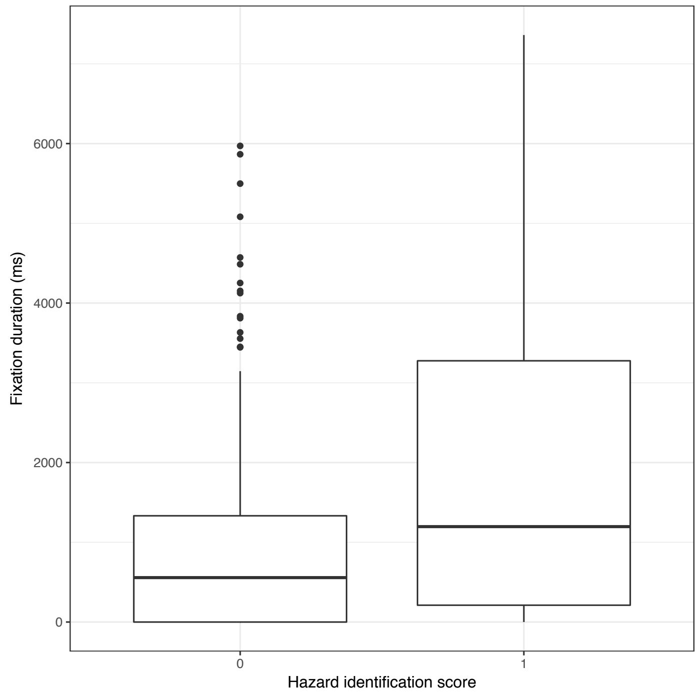


Figure **5- 6**: Distribution of fixation time per hazard identification (1 indicates correctly identified hazard, 0 indicates incorrectly identified hazard)

As it can be seen, the median fixation duration for the correctly identified hazard is slightly higher compared to the incorrectly identified hazard. A one tailed t-test was performed to confirm that the mean fixation duration is higher when participant correctly identified the hazard ($t=4.057$, p-value= 3.462e-05).

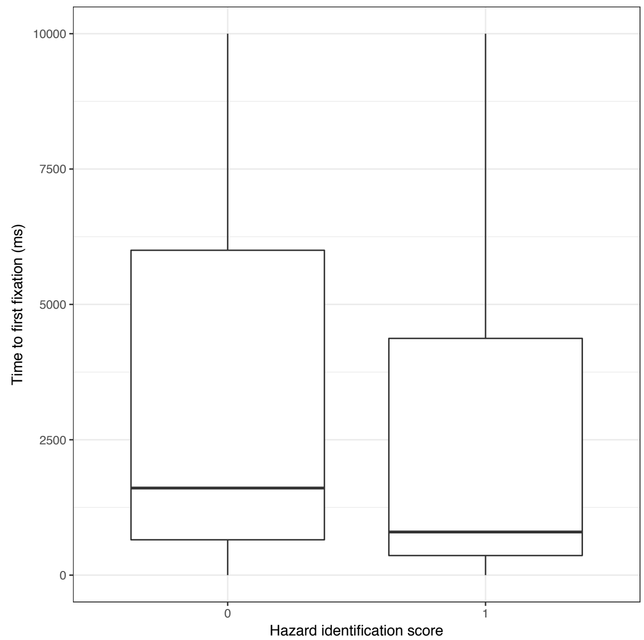


Figure **5- 7**: Time for first fixation per hazard identification (1 indicates correctly identified hazard, 0 indicates incorrectly identified hazard)

The same approach was applied to further study the first fixation time. Figure 5-7 show the Tukey box plot for distribution of the first fixation time. It can be seen that the first fixation time is shorter than when the participants correctly identified the hazard. Again, a one tailed t-test was performed to confirm the significance of this observation (t=-2.3193, p-value=0.016).

Correlation between hazard identification scores and fixation duration

A correlation analysis is performed on the data to measure the strength and direction of the relationship between the fixation duration and the hazard identification score. The Spearman's rank correlation was conducted between the fixation durations and the scores. The correlation coefficient is remarkably high (0.853) and statistically significant at the 95% confidence level.

Therefore, there is a very close relationship between the length of the time a participant spent looking at a hazard and the number of hazard identified correctly.

Visual attention and risk perception

In order to address objective 3 (which is understanding the relationship between construction worker's visual attention and risk perception based on sociodemographic data), the eye movement metrics are studied in two clusters obtained in previous section based on qualitative risk behavior of participants. This investigation has been done after examining the relationship between hazard identification scores and fixation duration. Figures 5-8 and 5-9 show the variation of the fixation duration and the time to first fixation in each cluster.

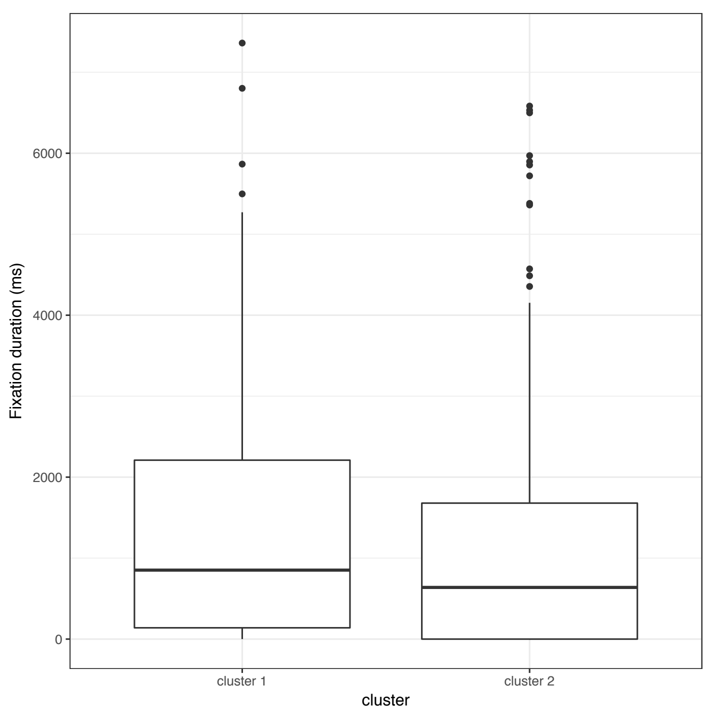


Figure **5- 8**: Fixation duration per cluster

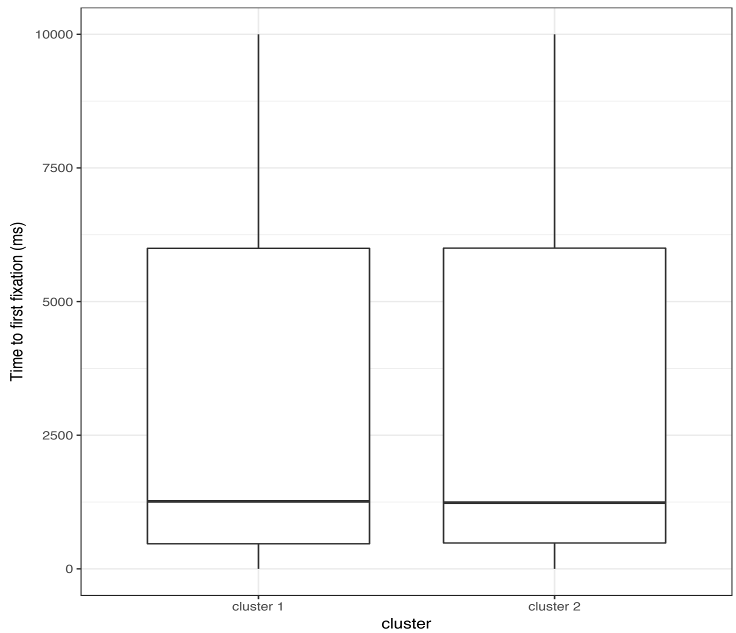


Figure **5- 9**: Time for first fixation per cluster

The results show that the time to first fixture is slightly higher and the fixation duration is slightly lower in cluster 1(inexperienced workers) compared to cluster 2 (experienced workers). A two-way student t-test was performed to confirm the significance between the two samples mean value (t-value = 0.0739, p-value =0.9441 and t=-0.9727, p-value=0.3652). The results indicate that there is no significant difference in fixation time and time to first fixation between the two clusters.

Relationship between BART test and severity score

The hypothesis is that the participants who are taking greater risks (based on the results of the BART experiment) would underestimate the level of danger while those who are less risk prone would overestimate the level of danger present in the safety photos.

A correlation analysis between the BART and severity scores is performed to test the hypothesis that participants with higher risk-taking tendencies would underestimate the level of danger while those who are risk-avoider would overestimate the level of danger present in the safety photos. The correlation analysis (r = 0.311) with 95% confidence interval (p-value=0.0534) indicated that the association between these two variables is not significant. Figure 5-10 shows the moderate relationship between these two variables.

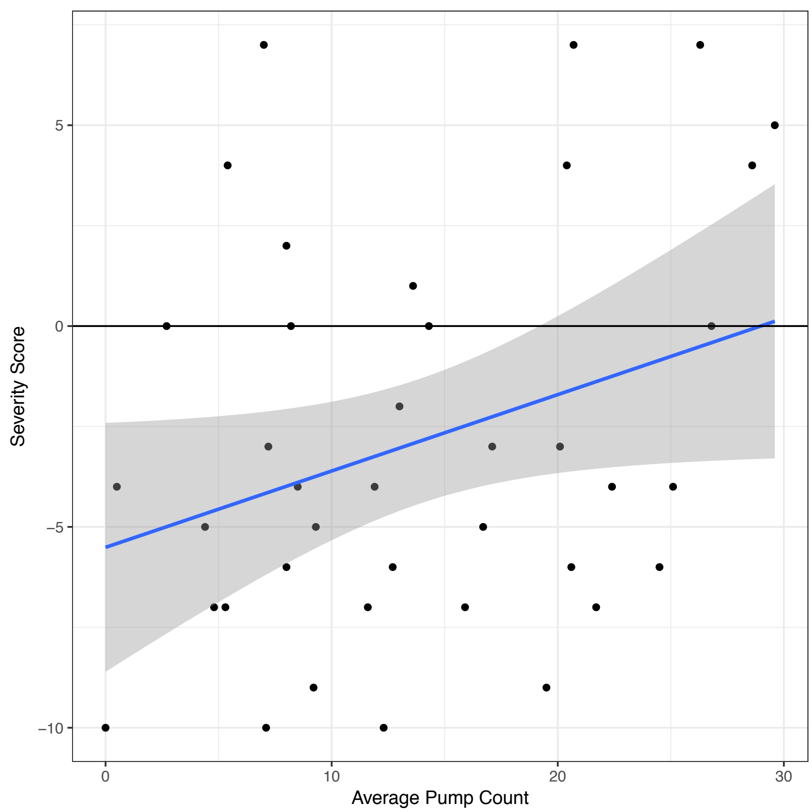


Figure **5- 10:** Relationships between the average number of pumps and severity score

Relationship between risk perception, severity score and hazard identification

Figure 5-11 shows the distribution of the hazard identification score in each cluster. Figure 5-12 show the distribution of severity score obtained by worker in experience and inexperienced cluster.

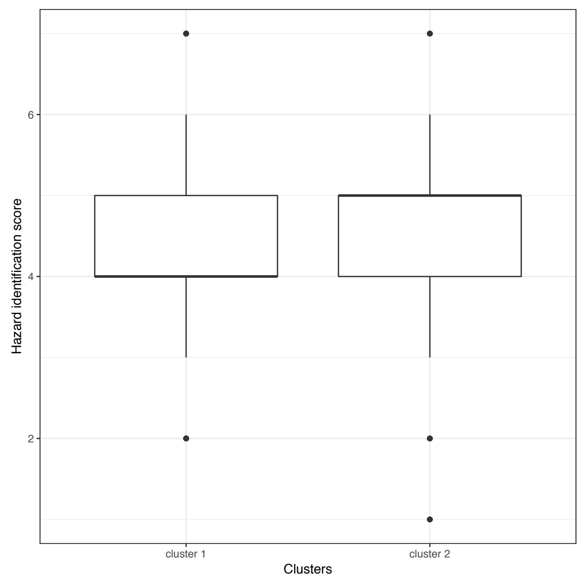


Figure **5- 11**: Hazard identification score per each cluster (cluster 1: inexperienced, cluster 2: experienced).

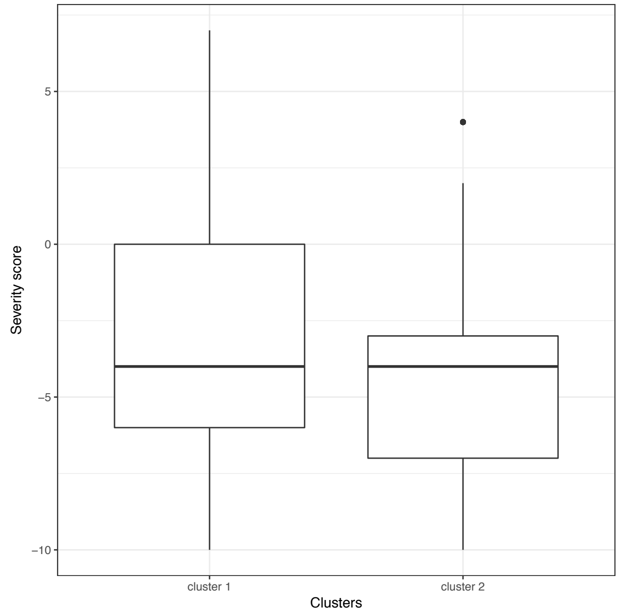


Figure **5- 12**: Severity score per each cluster

(cluster 1: inexperienced, cluster 2: experienced).

Two tailed Student t-test was performed to establish the difference between the hazard identification score and severity score in the two clusters (Table 5-8).

Table **5- 3**: Quantitative analysis of t-test for “hazards identification score and severity score”

	Group	Mean score	t-value	P-value
Hazard identification score	Cluster 1 (inexperienced)	4.476190	0.44174	0.6589
	Cluster 2 (experienced)	4.411765		
Severity score	Cluster 1 (inexperienced)	-2.457143	2.8504	0.004606
	Cluster 2 (experienced)	-3.823529		

As it can be seen, the difference between mean hazard identification score between two clusters is insignificant, and there’s no significant difference between mean score hazard identification scores in the two cluster. In addition, the mean difference between the severity score between the two cluster is significant and theirs is significant difference between mean severity score in the two cluster. A one tailed t-test (t-value=2.8504, P-value=0.002303) was performed (with the alternative hypothesis that the difference between mean severity score in two cluster is positive) which confirms that the cluster with higher risk perception overestimates the severity of hazardous situation compared to the cluster with lower risk perception.

Conclusions

This chapter address the objective 3 (Understanding construction workers' hazard identification ability (visual attention).

Based on the obtained results, it was found that:

- Hazard identification has a significant relationship to duration of fixation and the first time of fixation on the area of interest. The former indicated the intentional attention and later the bottom down and top down attention on the area of interest.
- Participants with higher risk-taking tendencies would underestimate the level of danger while those who are risk-avoider would overestimate the level of danger present in the safety photos.
- The relationship between risk perception and visual attention metrics were found be to inconclusive. Further studies such as hidden factor analysis could better determine if such relationship exist.
- Workers' risk perception has a direct relationship to severity score given by the workers to each hazardous situation. Workers' in more experienced cluster found to overestimate the hazardous situations while the inexperienced workers did the opposite.

Chapter 6

Conclusion and future research

Introduction

The construction industry is well-known for being a dangerous or highly hazardous industry, due to the high number of accidents and fatalities that occur on construction sites around the world. The risk of major injury in construction industry is approximately three times higher than in the manufacturing industries. In addition, the risk of fatality is around five times higher (1).

Generally, accidents at work happen either due to: lack of knowledge or training, lack of situation awareness, lack of supervision, lack of attention to follow the task safely, or the lack of controlled a sufficiently working environment (4). In construction, unsafe behavior is one of most important factor of accidents (5). Based on the information given by t Health and Safety at Work (HSE), about 90% of all fatal construction accident could have been prevented 70% of them by effective management action.

The effectiveness of human behavior in construction industry is playing an important role and it is depended on detailed knowledge and understanding of: (a) How a hazard and risk is perceived. (b) How a seen hazard is recognized (c) How a division must be made to avoid the hazard based on the risk tendency and personality (6).

According to (Ramsey) workers could act based on their risk and hazard perception at the jobsite, so safety improvement in the construction industry is the most appreciated beneficial effect of enhancing worker's risk and hazard perception. Therefore, systematic understanding of unsafe behavior has great potential to contribute to the reduction and prevention of injuries and fatalities in construction projects.

Therefore, the objectives of this study are to:

(1) Understanding construction workers' risk perception psychologically.

(2) Understanding construction workers' risk-taking capacity

(3) Understanding construction workers' hazard identification ability (visual attention)

(4) Understanding relationship between sociodemographic variables and construction workers' perception of risk, hazard and visual attention.

Results of Hypothesis Testing

(1) Construction worker's sociodemographic variables can help in understanding the perception of risk and hazard identification.

By investigating the relationships between sociodemographic variables and quantitative and qualitative risk perception, we have concluded that the sociodemographic information can be used to describe the workers' risk perception. Figure 4-6 showed that, the participants can be clusters in two groups with differing sociodemographic attributes based on their risk perception. Results indicated that experienced workers have more risk perception than inexperienced workers.

(2) Construction workers who are taking greater risks (based on the results of the BART experiment) has less risk perception andthey would underestimate the level of danger. However, those who are less risky has higher risk perception and they would overestimate the level of danger.

Figure 4-9 studied the relationship between pump count in BART in each cluster (experiment and less experiment participant). Experienced workers with more children has the higher risk perception and has less risk-taking tendency, while workers how have less working experience and less children, has less risk perception and higher risk taking behavior.

A correlation analysis between the BART test and severity scores (figure 5-7) is performed to test this hypothesis. Results showed that participants with higher risk-taking tendencies would underestimate the level of danger while those who are risk-avoider would overestimate the level of danger present in the safety photos.

(3) There is a positive relationship between construction workers' visual attention and risk perception. Construction workers with lower visual attention, have lower risk perception.

By studying the severity score and hazard identification score in two clusters (figure 5-12), it was concluded that there is a significant relationship between risk perception variables and severity score. Workers with higher risk perception overestimated the severity of the hazardous situations while the workers with lower risk perception underestimated the same hazards. In additions, the relationship between risk perception information and hazard identification score was found to be insignificant. This observation indicates that there are hidden factors influencing the workers' ability in identifying hazardous situations.

Research Contribution

- Abundant studies examine the risk perceived in many different areas, but not many studies have focused on the construction industry, and even less from standpoint of ergonomics and hygiene. Understanding construction workers' risk perception based on their sociodemographic attributes has significant implication due to the relationship between risk perception, self-protection behavior and safe behavior. (28, 29).
- This study present a new approach to understand and improve workers' safety at construction site using eye-tracking technology which has been accepted as a direct and continuous measure of attention.

At the best our knowledge, this study is the first in construction research on human safety behavior by connecting their visual attention, risk perception and sociodemographic attributes. Therefore, the results of this study can be used to develop an assessment tool to gauge how well construction workers understand safety hazard in a workplace to predict how, when and where an accident occurs.

Limitation of the study and future work

There are couple of limitations to the study that should be noted as follow:

- The population under study in eye tracking and BART experiment was approximately less than half of the sample population in the survey experiment. Therefore, some important analysis such as, relationship between workers hazard identification between different construction trade was not possible, due to limited number of samples in many trades.
- Since the application of eye tracking in construction industry is relatively new, unlike advertisement and human computer interaction, there are limited guide lines for design and conducting experiment with intention to quantify workers' visual attention and awareness.
- Further statistical analysis such as hidden factor and repeated measure analysis are required to study the relationship between visual attention, safety training and sociodemographic attributes in construction industry.

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