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Editorial

I am so honored to compose summaries about these remarkable articles in this issue of *Journal of Safety Health and Environmental Research (JSHER).*

In the first article, the authors Yorio and Wachter developed a theoretical argument regarding the important place that human-performance-focused safety and health (S&H) management practices serve within the comprehensive safety and health management system. Within their article, the authors proposed 10 distinct but interrelated S&H-specific high-performance work practices (HPWPs) that might be used by organizations to improve occupational S&H performance through human S&H performance. The authors hypothesized that the presence of individual S&H-HPWPs, as well as the system of S&H-HPWPs, would increase the task and team safety behaviors relevant to work in an interdependent context and subsequently reduce occupational injuries and illnesses.

To execute the study, organizational managers provided information to the researchers regarding the organizational structure and the number of recordable and lost-time injuries and illnesses each group experienced. Using structural equation modeling software, the authors found support for a conceptual path model in which the reduction in occupational injuries and illnesses by S&H-HPWPs was mediated by task and team safety proficiency behaviors. Interestingly, the authors found that team-focused safety behaviors had a stronger impact on the team's level of lost-time injuries and illnesses than did safety behaviors associated with individual tasks.

The findings support the premise that organizations can use these or similar practices as a component of their comprehensive HSMS to increase important worker safety behaviors and decrease the number of injuries and illnesses the group experiences. The findings verify that safety performance involves both individual and team behaviors that must be positively managed in order to accrue the benefits of having a safety and health management system in place. Further, the authors pointed out that that socially directed forms of safety behavior, an aspect of safety behavior that has received little attention in the S&H research community, might be a very important component to occupational injury and illness prevention.

In the second article, Wilkins, Chen and Jenkins explored the use of an instructional method known as translanguaging to deliver safety and health training to foreign-born workers of Hispanic origin. This research is important because foreign-born workers of Hispanic origin account for a disproportionately high number of accidents and injuries in the construction workplace. Regardless of their level of fluency or understanding of the English language, this vulnerable demographic of construction workers are most often subjected to safety and health training in English-only formats. The authors recruited a sample of 621 foreign-born workers of Hispanic origin around the New York City area and randomly assigned them to three groups. One-third of the participants were assigned to a learning environment wherein training was delivered in English; another one-third of the participants were assigned to a learning environment wherein training was delivered in Spanish; and the remaining participants were assigned to a learning environment wherein training was delivered through the process of translanguaging, an instructional method where speakers sporadically shift between English and Spanish.

Following the training, participants completed a posttest, and the scores were analyzed descriptively and correlated based on years of experience. The results revealed that foreign-born construction workers of Hispanic origin performed best on posttests when they received safety and health training in learning environments that incorporated the translanguaging instructional method. The authors also found that these workers performed better on posttests when the training was delivered in Spanish-only rather than in English-only learning environments. Whether as a cost-saving measure or a method to improve training effectiveness, the authors believe that these findings present an opportunity for human resources managers and training professionals to revisit how construction-industry safety and health training is delivered to foreign-born workers of Hispanic origin.

Finally, authors Anderson and McCoy measured the airborne methylene diphenyl diisocyanate (MDI) vapor or aerosol concentrations when MDI- and polymeric MDI (PMDI)-based Gorilla Glue® are manually applied by a consumer. The authors designed a work practice simulation study using Gorilla Glue®, while quantitatively evaluating airborne concentrations of MDI during standard and hypothetical maximal worst-case consumer use or work practices. Minimal literature regarding consumer use and ensuing exposure to isocyantes is available. Isocyanates are well known as a leading worldwide cause of occupational asthma.

Inhalational exposure to airborne isocyantes is highly dependent on the chemical composition of the materials and product usage, as well as the volume and surface areas of the isocyanate-containing materials utilized. Often, the generation of airborne isocyantes is also directly related to the vapor pressures of the individual compounds. Lower molecular weight and aliphatic isocyanates volatilize at room temperature, which may result in airborne vapors, while higher molecular weight isocyanates, including MDI, do not readily volatilize and become airborne at room temperature, particularly without spray application. Gorilla Glue® is an example of an uncured,

one-component, polyurethane adhesive containing a mixture of monomeric MDI and PMDI, which is designed and marketed as a waterproof, pourable adhesive for consumer use. The use and chemistry of Gorilla Glue® is materially different than materials containing isocyanates that are applied by spray processes in large volumes. Despite the lack of research on pourable isocyanate-containing adhesives, the regulation of MDI-containing consumer products continues nationally and internationally. EPA issued the MDI and Related Compound Action Plan (RIN 2070-ZA15). However, EPA has not recognized the unique chemical and toxicological differences between the consumer use of MDI-containing spray foam as compared to MDI-containing pourable adhesives, as well as the dramatic differences in the volume of the materials utilized. The method of use or application and the resulting volume of the material utilized are paramount since toxicology and exposure studies of MDI have been based primarily on occupational populations exposed to spray-applied products. The work practice simulation study conducted by Anderson and McCoy provided scientific data to affirmatively define the potential of whether inhalational exposure to MDI occurs during the standard and work case use of this adhesive product by a consumer.

I hope that you enjoy these interesting articles. As always, I look forward to hearing from you and welcome your submission of manuscripts to *JSHER*.

Yours sincerely,
Sang D. Choi, Ph.D., CSP
Managing Editor, JSHER

Safety-and-Health-Specific High-Performance Work Practices & Occupational Injury and Illness Prevention: The Mediating Role of Task & Team Safety Proficiency Behaviors

Patrick L. Yorio and Jan K. Wachter

Abstract

Using the high-performance work practice literature as a foundation, a theory of safety-and-health-specific high-performance work practices (S&H-HPWPs) was developed and subsequently tested using 62 groups of employees from 31 distinct organizations. It was hypothesized that the presence of individual S&H-HPWPs, as well as the system of S&H-HPWPs, would increase important group-level safety behaviors relevant to work in an interdependent context and subsequently reduce occupational injuries and illnesses. Although not all statistically significant, each of the individual practices positively correlated with task and team safety proficiency behaviors and negatively correlated with injuries and illnesses. Using structural equation modeling software, support was found for a conceptual path model in which the reduction in occupational injuries and illnesses by S&H-HPWPs was mediated by task and team safety proficiency behaviors.

Keywords
human safety performance, high-performance work systems, safety and health management systems, human factors, occupational injury and illness prevention

Introduction

The theoretical and empirical links between high-performance work practices (HPWPs) and occupational safety have been previously examined (Barling & Zacharatos, 1999; Parker, Axtell & Turner, 2001; Zacharatos, Barling & Iverson, 2005). As stated by Parker, et al., 2001, this literature is grounded in the premise that traditional HPWPs used to manage relevant performance and efficiency behaviors are also likely to influence important safety behaviors. The traditional HPWPs considered in these models consist of job autonomy, high-quality jobs, employment security, transformational leadership, extensive training, information sharing, measurement of management practices, safety contingent compensation, selective hiring, and reduced status distinctions. The works cited provide support for the use of strategic human resource management practices to reduce unsafe behaviors and increase overall organizational safety performance.

Although evidence suggests that general HPWPs can influence occupational safety, organizations often rely on a set of management practices specifically designed to manage human safety performance as a subset of a comprehensive safety and health management (Makin & Winder, 2008). In the current study, HPWP theory is applied to the ideas behind safety and health (S&H) management practices. Through a literature review and qualitative research process, a list of 10 practices was generated. The list consists of those practices that were consistently identified and recognized by organizations as being critical to managing human safety performance in their organizations:

- •employee involvement;
- •pre- and posttask safety reviews;
- •safe work procedures;
- •hiring for safety;
- •cooperation facilitation;
- •safety training;
- •information sharing;
- •accident investigation;
- •detection and monitoring;
- •safety task assignment.

Throughout this article, these practices are referred to as safety-and-health-specific high-performance work practices (S&H-HPWPs).

A theory postulated by Evans and Davis (2005) suggests that HPWPs are increasingly important in today's interdependent workplace because they enhance both individual task as well as socially directed forms of performance. Although theory relating socially directed forms of behavior to organizational performance has been supported empirically within the organizational

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L.psychology literature (Adler & Kwon, 2002; Leana & Pil, 2006; Nahapiet & Ghoshal, 1998), these types of behaviors have rarely been examined in the context of organizational safety performance. In the current study, Evans and Davis's (2005) theory was extended to the context of organizational safety performance, and it was argued that S&H-HPWPs are important for achieving optimum levels of collective safety performance in interdependent contexts and effectively operate through both individual task and socially directed forms of safety behavior.

This manuscript is structured as follows. S&H-HPWPs are first defined and theoretically operationalized through the HPWP strategic human resource management literature. Second, two important forms of safety behavior are operationalized through an adaption of Griffin, Neal and Parker's (2007) model for job role performance relevant to interdependent work processes. Third, theory is developed regarding the mechanisms through which each of the individual practices, as well as the complete system of S&H-HPWPs, operates to improve the operationalized safety behaviors and reduce levels of occupational injuries and illnesses. Fourth, the results of each of the tested hypotheses are presented along with the results derived from an integrated path model that examined the impact of S&H-HPWPs on group-level occupational injuries through group-level task and team safety proficiency behaviors. The study's findings and limitations are then discussed.

S&H-HPWPs

Management theorists have spent considerable time developing the rationale as to how strategic human resource practices impact organizational performance. The fundamental idea in this literature is that employees represent a form of capital that organizations can use to gain a competitive advantage in the marketplace. When the complete, unitary system of practices is considered, it is referred to as a system of HPWP (Guthrie, 2001; Huselid, 1995).

HPWP systems can be conceptualized as a group of separate but interconnected human resource practices that collectively recruit, select, develop, motivate, and retain employees (Way, 2002). HPWP systems emphasize that organizations can gain a sustainable competitive advantage through the utilization of strategic synergistic human resource practices. HPWP theory further argues that employees are capable of continuous improvement and, when motivated, will perform at higher levels (Pfeffer, 1998). Based on theory regarding their inimitable properties and empirical evidence that demonstrates their positive impact on various forms of organizational performance (Guthrie, 2001; Huselid, 1995), management theorists have been able to establish HPWP themselves as a source of competitive advantage.

HPWP theory can be applied to S&H management practices and systems to gain a more precise understanding as to how they uniquely and interactively operate. Based on the HPWP theory presented earlier, it can be argued that S&H management practices are a subset of human resource practices that as a unitary system influence employee safety-focused knowledge, skills, motivation, decision making, attitudes and perceptions. S&H management practices and systems also encompass high-commitment and high-involvement elements and are strongly grounded in the theories postulating employees as organizational resources that are tied to the firm's ability to compete in the marketplace (Barling & Hutchinson, 2000). These S&H management practices can be conceptualized as global data points and act to create a context in which employees carry out their work. In this manner, management practices differ from relevant compositional forms of context (e.g., safety climate or culture), and can be considered as the proximal antecedent of them. This understanding is consistent with the human resource management literature's argument that human resource policies and procedures are a primary source of measures of organizational climate (Gelade & Ivery, 2003; Rogg, Schmidt, Shull & Schmitt, 2001).

Using the existing safety management practice literature (i.e., Arboleda, Morrow, Crum & Shelley, 2003; Makin & Winder, 2008; McDonald, Corrigan, Daly & Cromie, 2000; Robson, et al, 2008; Vassie & Lucas, 2001; Vredenburgh, 2002) as a starting point for further investigation, a series of exploratory interviews was conducted ith representatives from large U.S. domestic organizations, multinational organizations and human performance consulting firms. Using this process the following practices were identified as important S&H management practices for improving human safety performance: pre- and posttask safety reviews, safe work procedures, hiring practices for safety, cooperation facilitation, employment involvement in implementing specific safety-related processes, safety training, communication and information sharing, accident investigation, detection and monitoring, and safe task assignment. It is recognized that this list is not comprehensive and that additional practices may be used. These practices were included primarily because they were consistently identified in the literature and through the qualitative research process as practices used to improve human safety performance.

Safety Behaviors in an Interdependent Context

Griffin, et al. (2007) argue that one major change taking place in today's workplace is the increasing interdependence of work. Interdependence "determines whether an individual can be effective by simply managing the responsibilities of his or her role as an individual within an organization or also needs to act to support the broader social context of the organization" (Griffin, et al., 2007, p. 330). Interdependence arises when individuals in a work group need to cooperate to achieve shared goals. In interdependent systems, the behavior of an individual has an impact not only on the effectiveness of that individual, but also on the effectiveness of his/her group and the organization as a whole.

This increasing interdependency of work is suspected to influence the nature of workplace safety performance. In the context of safety performance, all employees share in the responsibility to create a safe work environment. Each individual in an interdependent context must make work decisions to minimize unsafe acts or conditions to minimize the risk for

other individuals in the collective. Often, without the physical and planning assistance of coworkers, manual tasks default to not being completed safely. Further, coworkers often rely on one another to ensure that machinery and equipment necessary for task execution is constructed and maintained in a safe manner. Finally, each individual accident or injury impacts the group safety performance and organizational safety performance as a whole.

Theory exists to support the premise that HPWPs can influence both individual task performance and socially directed forms of behavior. Evans and Davis (2005) argue that the use of HPWPs not only enhances individual-related task performance within an organization, but also changes the nature of employee relationships within the collective. Griffin, et al. (2007) identify a total of nine dimensions of work role performance to account for the context of uncertainty and interdependence. Two of the dimensions proposed by Griffin, et al. (2007) are particularly relevant to exploring the theory proposed by Evans and Davis (2005): individual task proficiency and team proficiency.

Proficiency is a term that Griffin, et al. (2007) designed to reflect the extent to which members of a group meet minimum knowledge, skill and ability requirements and are motivated to meet formalized role requirements as displayed through their behaviors. As such, task safety proficiency reflects the consistent and proper execution of the safe work behaviors required of individuals and team safety proficiency reflects the minimum cooperative behavioral elements needed to ensure the safety of the collective. As such, it is expected that both task and team safety proficiency can be maximized through S&H-HPWPs.

Individual S&H-HPWPs & Task & Team Safety Proficiency Behaviors

In this section, each practice is individually discussed in terms of the mechanisms by which it is believed to positively influence task and team safety behaviors performance and negatively influence workplace injuries and illnesses. Consistent with the HPWP literature, each practice is expected to work in different ways and when combined into a system, the system and its practices are expected to wholly and synergistically improve the safety performance of organizations (Evans & Davis, 2005).

Employee Involvement in Specific S&H-Related Processes

HPWP theory suggests that even when the necessary prerequisites of knowledge, skills, abilities and motivation are satisfied, employees are incapable of deploying their competencies unless the organization provides them the opportunity to do so (Bailey, 1993; Combs, Liu, Hall & Ketchen, 2006; Huselid, 1995). Employee involvement encompasses self-managed teams, employee influence of practice design, decentralized decision making, and formal suggestion and feedback systems. The benefits to employee involvement practices are conceivably increased attitudinal and behavioral adoption of various practices, greater satisfaction with decisions made and the results of those decisions, and ownership and identification with the outcomes of relevant practices and decisions (Freeman, Kleiner & Ostroff, 2000). Employee influence and/or participation in developing and implementing safety management practices, processes, programs and procedures can hypothetically function in a similar fashion. It is hypothesized that employee involvement can play a critical role in human safety performance management.

Hypothesis 1: Employee involvement will positively correlate with task and team safety proficiency and negatively with occupational injuries and illnesses.

Pre- & Posttask Safety Reviews

All work tasks are associated with some degree of risk. When employees perform routine tasks they are likely to become complacent and fall into the cognitive decision-making traps and biases (Zohar & Erev, 2007). Pretask safety reviews are designed to cognitively prime a person or group of persons for the safe execution of a task. Topics covered during pretask safety briefings can include potential error traps and individual and coordination performance modes of operation that apply to the task itself. During these briefings, roles and responsibilities, conditions, PPE requirements and emergency procedures can also be discussed (Wachter & Yorio, 2013). Posttask reviews are designed to uncover lessons learned from the operation of the task and can be used to review job conditions, identify program gaps and discuss corrective actions (Wachter & Yorio, 2013).

Hypothesis 2: Pre- and posttask safety reviews will positively correlate with task and team safety proficiency and negatively with occupational injuries and illnesses.

Safe Work Procedures

Safe procedures provide the steps that employees must take to execute a task successfully and free of injury, illness and incident. When organizations take the time to ensure that safe work procedures are developed, they are also providing a form of role clarity (as opposed to ambiguity) to employees (Argote & Ingman, 2000; Katz-Navon, Naveh & Stern, 2005). Safe procedures communicate to employees exactly how they are to carry out their work. In the absence of such clarity, employees are forced to guess as to how the organization desires them to carry out their work. When competing priorities (e.g., efficiency vs. safety) exist, task and role clarity are essential in creating a properly functioning workforce. Role clarification in general has been associated with safety performance (Hemingway & Smith, 1999; Zacharatos, Barling & Iverson, 2005).

Hypothesis 3: Safe work procedures will positively correlate with task and team safety proficiency and negatively with occupational injuries and illnesses.

Hiring Practices for Safety

Hiring practices for safety function by: 1) selecting those employees who are less likely to get injured because they have

an intrinsic value of working safely; 2) selecting employees who possess the necessary physical and mental capacities to carry out tasks safely; and 3) instilling the organizational priority and value of safety prior to a job offer (Polyhart, Weekley & Baughman, 2006; Vredenburgh, 2002; Zacharatos, et al., 2005). Hiring for safety is a management practice that can be implemented through elements such as multiple standardized interviews and assessments designed to better understand the prospective employee's attitude and personality; a process to evaluate and instill the value of safety prior to hire; and a means to better ensure the hiring of physically and mentally suitable employees (Zacharatos, et al., 2005).

Hypothesis 4: Hiring for safety will positively correlate with task and team safety proficiency and negatively with occupational injuries and illnesses.

Cooperation Facilitation

Safety can be viewed as a personal and collective endeavor especially in today's workplace where tasks are becoming increasingly interdependent. Where tasks are interdependent, employees need to rely on one another for information and cooperation to perform tasks successfully and without incident (Griffin, et al., 2007). An increasing concern for current safety programs is to develop formal practices that promote safety cooperation and information sharing for the benefit of the collective. When organizations actively facilitate cooperation, they engage the workforce in socially directed forms of behavior (McAllister, 1995; Schalk & Curseu, 2010) that can include safety behaviors as well as important safety information sharing and communications that can enhance the safety for the collective in interdependent task execution.

Cooperation facilitation is somewhat consistent with the idea that a team-based organizational structure can be used to prevent workplace accidents (Zacharatos, et al., 2005). An organizational structure that utilizes teamwork exemplifies the interdependency of safety performance in terms of actual task completion and the cooperation necessary to solve collective safety problems (Geller, Roberts & Gilmore, 1996).

Hypothesis 5: Cooperation facilitation will positively correlate with task and team safety proficiency and negatively with occupational injuries and illnesses.

Safety Training

Theory and research support the premise that safety knowledge, skills and abilities are a function of education and training (e.g., Burke, Sarpy, Tesluk & Smith-Crowe, 2001; Campbell, 1990). Evans and Davis (2005) note that, after organizational entry, training is designed to enhance both the technical and interpersonal skills of employees that can lead to more competent and reliable behavior. As employee behavior becomes more reliable, trust among the collective workforce is also enhanced which, in turn, can lead to increased cooperation and information sharing. Further, "trust should reduce concerns over equivalence and immediacy of exchanges, resulting in generalized norms of reciprocity" (Evans & Davis, 2005, p. 765).

Safety training can act in the same way. As safety training directly increases the safety-related knowledge corresponding to the occupational risks posed to workers in job tasks, and workers display that knowledge through their behaviors, it can create a work atmosphere characterized by trust and an awareness of how individual safe behavior can impact the collective.

Hypothesis 6: Safety training will positively correlate with task and team safety proficiency and negatively with occupational injuries and illnesses.

Communication & Information Sharing

Communication and information sharing is a safety management practice that uses mechanisms to emphasize how to apply safety knowledge, increase awareness, and promote the importance of individual and interdependent safe work. Organizations might use print media (e.g., posters and payroll stuffers) to increase cognitive awareness of safe work and emphasize its importance or hold formal meetings designed to verbally convey information and exchange ideas with the workforce. Communication and information-sharing practices have been formally linked to safety performance and have been hypothesized to enhance both vertical and horizontal ties (Zacharatos, et al., 2005). Information sharing is characterized by mutual trust between parties where ideas surrounding the organizational safety program can be freely exchanged. Numerous empirical studies show support for the benefits of open communication on safety performance (Hofmann & Mark, 2006; Hofmann & Morgeson, 1999; Katz-Navon, Naveh & Stern, 2005;).

Hypothesis 7: Safe work procedures will positively correlate with task and team safety proficiency and negatively with occupational injuries and illnesses.

Accident Investigation

When safety incidents occur organizations can investigate them in order to determine how and why the incidents occurred with the goal of altering the causes in the chain of events that led to the incidents. The goal then, is to prevent the potential of future similar accidents. The investigation results are used to modify the work environment and safety management system and to adjust or fine tune other practices that make up the system (Phimister, Oktem, Klindorfer & Kunreuther, 2003). Accident investigation may be considered a continuous improvement element in the complete system of safety management practices; as such, it serves a critical role in the ongoing effort of injury and illnesses prevention (Phimister, et al., 2003).

Hypothesis 8: Accident investigation will positively correlate with task and team safety proficiency and negatively with occupational injuries and illnesses.

Detection & Monitoring

The detection and monitoring safety management practice is grounded in an extrinsic model of human behavior motivation in which people primarily respond to external contingencies in their environment. It is based on the premise that safe work

behavior is a function of the costs and benefits people associate with working safely or not (Tyler & Bladder, 2005). In organization and legal settings, detection and monitoring (a command-and-control-related strategy) has consistently been found to influence rule-breaking behavior (MacCoun, 1993; Tyler, 1990; Tyler & Bladder, 2005) and undermine intrinsic motivation (Deci & Ryan, 1985; 1987). However, in the context of routinely required individual and interdependent safe work performance, detection and monitoring can play a key role in facilitating safe work behavior.

Safety behaviors are typically defined and mandated by the regulatory or organizational environment. Managers and employees generally understand that worker noncompliance with safe work rules may result in organization-level sanctions in the form of fines or poor reputation and employee injury. Because of the possibility of severe organizational-, group- and individual-level implications, managers must ensure that employees behave safely. Further, in the case of high-quality relationships between managers and employees, detection and monitoring may be expressed in terms of a legitimate concern for employeees' physical welfare.

Based on this line of reasoning, it is suspected that detection and monitoring of safe work behavior and environmental conditions that could cause unsafe behaviors can play a key role in human safety performance. Managers who display a consistent emphasis on adherence to safe work rules promote shared perceptions among the group concerning the priority of working safely. Further, in the context of safety, detection and monitoring may actually increase intrinsic motivation as workers perceive a legitimate concern for their welfare.

Hypothesis 9: Detection and monitoring will positively correlate with task and team safety proficiency and negatively with occupational injuries and illnesses.

Safe Task Assignment

Minimizing distractions through safe task assignment can be a critical element to ensure that employees execute individual and interdependent tasks efficiently and in a safe manner (Yorio & Wachter, 2013). Distractions act by directing an employee's attention to something other than the task at hand (Jett & George, 2003). When employees execute safety sensitive tasks, distractions can result in inadvertent risky and unsafe behaviors increasing the probability of incident (Norman, 1981; Wagenaar, Hudson & Reason, 1990). For example, fatigue, stress, multitasking, poor physical condition and being new to a task, all embody sources capable of distracting employees away from the task at hand and the ability to execute it in a safe manner. When these distractions are present, there is an increase in the probability of human error. Safe task assignment takes these sources into account prior to task assignment such that distractions and the likelihood of error in task execution are minimized.

Hypothesis 10: Safe task assignment will positively correlate with task and team safety proficiency and negatively with occupational injuries and illnesses.

Systems of S&H-HPWPs

Although these safety management practices are hypothesized to work uniquely to improve human safety performance, they seldom exist and function individually. They are most often administered in combination, representing a complete and unitary system of interconnected and synergistic practices. When the system of safety practices is considered, they can be conceptualized as a group of separate but connected human resource practices that collectively define safety requirements, emphasize the priority and value of working safely, motivate employees to work safely, and encourage cooperation among the workforce for the benefit of the collective.

Hypothesis 11: Systems of S&H-HPWPs will positively correlate with task and team safety proficiency and negatively with occupational injuries and illnesses.

An Integrated Path Model

The integrated model stems from the idea that S&H-HPWPs influence collective occupational injuries and illnesses through aggregate employee safety behaviors as operationalized through two dimensions of Griffin, et al.'s (2007) model of job performance relevant to work in an interdependent context (task and team safety proficiency). These forms of collective safety behavior are suspected to positively covary with the system of S&H-HPWPs and be the proximal antecedent of occupational injuries and illnesses. Figure 1 (p. 128) depicts the conceptual model.

The proposed model shows a mediated relationship with the absence of direct paths between S&H-HPWPs and the two categories of occupational injuries and illnesses. The figure reflects the hypothesis that the operationalized forms of task and team behavior will mediate the relationship between S&H-HPWPs and the categories of occupational injuries and illnesses. The figure also depicts the structural hypothesis that both forms of displayed safe behavior will covary. Finally, because lost-time accidents are a subset of OSHA recordable accidents, these two measures will necessarily covary.

Method

Sample

Through established professional networks (e.g., ASSE, Society of Human Resource Management) as well as through open invitation, the current research study was publicized to organizations. Approximately 44 establishments accepted the invitation to participate in the study. Of those, 31 involved safety critical operations (n = 31). Light and heavy manufacturing, nuclear power research and production, and mining were industries represented in the sample. These 31 establishments were asked to select two interdependent departments within their establishment to participate in the study.

The authors worked with the participating organizations to select groups that share similar tasks, the same production goals and with members who routinely need to work interdependently to achieve production goals. Each of the 62 groups completed two different surveys. The first survey measured

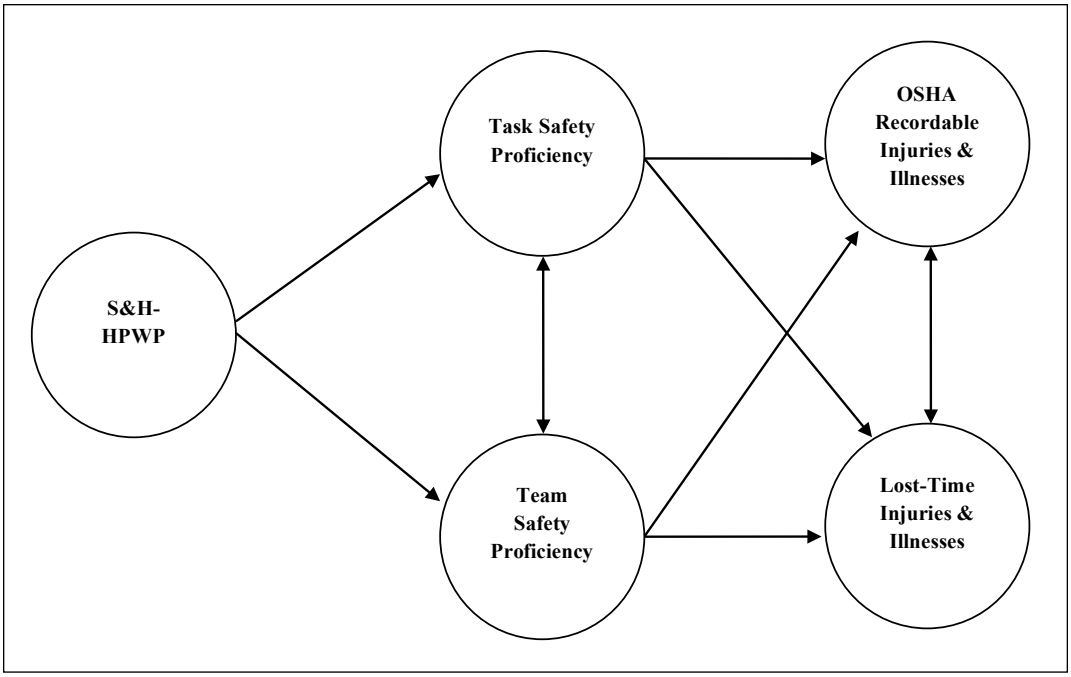

Figure 1 Conceptual model

the characteristics of S&H-HPWPs. The S&H-HPWP survey was administered to multiple group managers and supervisors independently in order to counteract potential bias in rating of human resource practices (Wright, Gardner, Moynihan & Park, 2001). A total of 205 department managers completed the survey (average number of managers per group 3.3, range 2 to 5). Another survey was completed by employees within each group which collected information regarding their level of task and team safety proficiency behaviors. A total of 1,515 employees completed surveys (average per group 24.4, range 13 to 34).

Measures

S&H-HPWPs: Presence and characteristics of S&H-HPWPs were measured using a composite of multiple questions. Prior to administration, questions were generated through a group discussion, qualitative approach with content experts such as safety and health managers, human resource managers, human performance consultants and corporate strategic advisors. Starting with a list of items gathered through safety management practice literature (see searlier references), the authors asked these representatives to critically consider each item, generate any additional items, and or suggest the removal of irrelevant items such that the end product represented the most effective way each practice is administered.

The total number of survey items designed to reflect the S&H-HPWPs was 51. Within the participating organization, managers were asked to evaluate the degree to which each item was relied upon as a key S&H management tool. A complete list of survey items used to assess each practice is included in the appendix of this article (pp. 133-134).

For each group, the mean of the managers' ratings was used to reflect each of the practice constructs. Within the management practice literature, when HPWPs are researched as a unitary system an additive approach is utilized (Becker & Huselid, 1998; Huselid, 1995; Zacharatos, et al., 2005). Consistent with this approach, the system of S&H-HPWPs was calculated by summing each of the practice composites for each group. Each individual practice displayed an acceptable level of internal consistency (Cronbach's $\alpha > .78$). The unitary system of S&H-HPWPs had a good level of internal consistency as well (Chronbach's $\alpha = .92$).

Occupational Injuries and Illnesses: The total number of OSHA recordable and lost-time injuries and illnesses (i.e., days away from work, restricted work, transferred work) that each group experienced over the previous 6 months was obtained from the organizations. It was not possible to obtain the exact number of employee hours worked within each group studied; therefore, incidence rates based on a function of hours worked could not be computed and used. Instead, the injuries and illnesses outcome was calculated as a function of the actual number of employees working within each group (i.e., calculated by the total number of injuries in each category—recordable or lost time—divided by the number of employees in that group). This value, essentially the mean number of injuries and illnesses each employee experienced in each group, was used in order to offset potential variation in the outcome due to different group sizes.

Task and Team Safety Performance: Both task and team safety proficiency items were adapted from the items used in Griffin, et al., (2007) designed to measure the dimensions and elements of work role performance. To measure task safety proficiency, each employee was asked to evaluate the following three items on a five-point scalle, strongly disagree to strongly agree:

•I carry out their core safety requirements of their job.

•I complete my core tasks using the standard safety procedures.

•I ensure that my work tasks are completed safely.

To measure team safety proficiency, the same five-point scale was used and the following statements were evaluated by each employee:

•I coordinate with others on safety issues for the benefit of the group.

•I communicate effectively with my coworkers on critical safety issues.

•I provide help to my coworkers when asked or needed for the benefit of everyone's safety.

Each construct displayed good internal consistency within

the sample (task safety proficiency, $\alpha = .91$; team safety proficiency, $\alpha = .89$).

In an interdependent context consistent behaviors between members are expected to emerge through theoretical processes such as social exchange, social influence and socialization (Festinger, 1957; Kozlowski & Klein, 2000; Moreland & Levine, 1982). As such, Kozlowski and Klein (2000) suggest that the mean is an appropriate summarization of behavioral constructs when combined with traditional agreement and inter-rater reliability statistics. The mean for each group was used in lieu of acceptable levels of within-unit agreement and between unit variance and interclass correlations (Bliese, 2000).

To calculate these statistics to support aggregation composites of each performance dimension (task and team) were first created. ANOVA's were then executed and values for ICC(1) and ICC(2) for each construct were obtained. LeBreton and Senter (2008) suggest that ICCs can be used to justify aggregation of individual level constructs into an operationalize group-level construct, and provide information regarding both the level of agreement and reliability of the group-level measurement. For task safety proficiency, the *F* statistic was 3.80, $p < .01$, and ICC(1) and ICC(2) were .09 and .69, respectively. For team safety proficiency, the *F* statistic was 2.95, $p < .01$, and ICC(1) and ICC(2) were .07 and .64, respectively. These values for the ICC(1) and the ICC(2) provide necessary justification for aggregation of the individually measured behaviors to a group-level construct (LeBreton & Senter, 2008).

Results

To test hypotheses 1 through 11, each individual S&H-HPWP and the system of S&H-HPWP was correlated with task and team safety proficiency and both forms of occupational injuries and illnesses (total recordable cases and lost-time cases). Table 1 shows that each of the individual S&H-HPWPs is related, in the direction expected, to task and team safety proficiency as well as recordable and lost-time injuries and illnesses. However, because of the small sample size (i.e., the number of groups in the study was equal to 62) and associated lack of power, correlations had to be above or below .25 to reach significance at the .05 level. It should be noted that attempts to increase the sample size were made; however, few additional organizations were willing to participate in the survey due to concerns over logistics and survey execution time. As such six of the 10 individual practices were significantly associated with increased task safety proficiency behaviors (exceptions were safe task assignment, accident investigations, safety training, and hiring for safety). Similarly, six of the 10 practices were significantly related to increased group-level team safety proficiency (nonsignificant S&H-HPWPs were identical to task safety proficiency). The system of S&H-HPWPs was significantly and positively related to both task and team safety proficiency behaviors.

As shown in Table 1, each of the practices was negatively associated with both recordable and lost-time injuries and illnesses. Each of the practices displayed a significant negative association with recordable injuries and illnesses except accident investigation and hiring for safety. The only S&H-HPWP not significantly associated with lost-time injuries and illnesses was hiring for safety. Further, the system of S&H-HPWPs was significantly and negatively related to both recordable and lost-time injuries and illnesses. Collectively, these findings provide partial support for hypotheses 1 through 11.

The system of S&H-HPWPs, group-level task and team safety proficiency, and recordable and lost-time injuries and illnesses were incorporated within the hypothesized path model. These variables are moderately correlated and significant in the direction expected. These correlations provide initial support for the hypothesized structural model.

The path model was analyzed using EQS (Bentler, 1985; 1995). A path model was chosen (as opposed to a structural model) because of the small number of groups available for the study. The path model approach allows for the assessment of goodness-of-fit for the model as well as parameter estimates in a multiple regression framework. Through a decomposition of effects into total, direct and indirect effects, the path model approach also allows for an appropriate test of mediation.

The hypothesized model fit the data excellently. The observed and model covariance matrices were not significantly

	Mean	SD	1)	2)	3)	4)	5)	6)	7)	8)	9)	10)	11)	12)	13)	14)
1) System of S&H-HPWPs	46.96	5.23														
2) Safe Work Procedures	4.67	.83	.77													
3) Employee Involvement	4.96	.99	.70	.60												
4) Safe Task Assignment	5.10	.93	.68	.49	.29											
5) Pre-Post Task Review	5.55	1.02	.78	.49	.39	.52										
6) Detection and Monitoring	4.45	.70	.74	.72	.65	.36	.41									
7) Accident Investigation	3.76	1.27	.56	.30	.05	.46	.54	.24								
8) Information Sharing	5.96	.75	.80	.60	.57	.36	.59	.70	.29							
9) Safety Training	4.21	.64	.64	.37	.20	.54	.52	.30	.80	.40						
10) Cooperation Facilitation	3.99	.52	.85	.64	.64	.46	.56	.60	.45	.72	.67					
11) Hiring for Safety	4.31	.64	.26	.18	.11	.34	.16	.05	.40	.08	.27	.01				
12) Task Safety Proficiency	4.02	.25	.42	.43	.29	.20	.30	.40	.11	.35	.12	.37	.11			
13) Team Safety Proficiency	3.97	.24	.44	.40	.34	.18	.28	.38	.16	.43	.18	.48	.03	.70		
14) Recordable Accidents	1.13	.18	-.36	-.31	-.30	-.31	-.31	-.31	-.20	-.30	-.28	-.30	-.08	-.40	-.45	
15) Lost Time Accidents	1.07	.10	-.32	-.27	-.29	-.30	-.28	-.30	-.25	-.27	-.29	-.33	-.21	-.39	-.47	.83

Note: N = 62 groups. All correlations above or below .25 are significant at the .05 level. All correlations above or below .33 are significant at the .01 level. S&H-HPWP is the system of safety and health-specific high performance work practices.

Table 1 Descriptive statistics and correlation table

different, χ^2 (2, N = 62) = .21, ns. Further, the fit indices indicated an excellent fit to the data, CFI = .99, GFI = .99, RMSEA = .01. Two additional models were tested: one with a single pathway from S&H-HPWPs to recordable injuries and illnesses and the other with a single pathway from S&H-HPWPs to lost-time injuries and illnesses. Neither alternative model provided a significantly better fit to the data than the conceptual model.

The hypothesized structural model included only indirect pathways between S&H-HPWP and both forms of occupational injuries and illnesses. As such, six relevant regression pathways are of interest. These pathways are reported in Table 2. Table 2 reports the following information from the path model corresponding to each predictive pathway: the unstandardized regression coefficient (B); the standardized regression coefficient (β); the value of the z test statistic for the regression coefficient (Z); the significance level for the regression coefficient (p); and the amount of variance explained in the construct by the predictors with a predictive pathway leading to the construct (R^2). The correlations between the proficiency behavior constructs and the injury outcomes (i.e., the double headed arrows in Figure 1) are not reported in Table 2. However, recordable and lost-time accidents were correlated significantly at .71 and both forms of S&H proficiency behavior were correlated at .67.

As shown in Table 2, there was a significant prediction of both task and team safety proficiency by S&H-HPWPs, β = .58, z = 5.49, p < .01, R^2 = .33 and β = .52, z = 4.81, p < .01, R^2 = .28, respectively. There was a significant prediction of recordable injuries and illnesses by both task and team safety proficiency, R^2 = .40. Task and social safety proficiency negatively and significantly predicted the recordable cases, β = -.28, z = -2.10, p = .03 and β = -.43, z = -2.80, p < .01, respectively. Task and team safety proficiency also negatively predicted lost-time accidents, R^2 = .41, but only the path between team safety proficiency and the lost-time injuries and illnesses was significant, β = -.48, -3.11, p < .01. The pathway between task safety proficiency and lost-time incidents was not significant.

Testing for mediation in a single model through fit statistic comparisons was not possible because two additional pathways between S&H-HPWP and both recordable and lost-time accidents were necessary. Because the conceptual model had only 2 degrees of freedom (2 df) these two additional pathways create a model that is just identified. ["Just identified" refers to a path model in which all of the available free parameters are estimated resulting in zero degrees of freedom and 'perfect' model fit. In this instance, the parameter estimates are estimated accurately but, because of perfect fit, the fit statistics are not applicable. See Baker (1995) and Bollen (1987) for a discussion regarding the methods used.]

This model allows for the accurate interpretation of parameter estimates but provides no fit statistics. For this reason, the model was saturated and the total, direct and indirect effects to test for the mediation hypothesis were interpreted. The parameter estimates corresponding to the test for mediation (the total, direct and indirect estimates) are reported in Table 3. The results of the test show that task safety proficiency and team safety proficiency together almost fully mediate the relationship between S&H-HPWPs and both recordable and lost-time accidents. The direct effect of S&H-HPWP on recordable accidents, β = -.046, ns, is approximately 10% of the total effect of the relationship, β = -.396, p = <.01. The indirect effect through both forms of group-level safety proficiency is significant, β = -.350, p < .01. A similar pattern is revealed in the relationship between S&H-HPWP and lost-time accidents. The direct effect, β = -.012, ns, is approximately 3% of the total effect, -.373, p < .01, while the indirect effect is β = -.361, p < .01. These results support the mediation hypothesis.

Discussion & Conclusion

In this research, the S&H-specific management practices used by organizations to improve organizational safety performance through human safety performance were first identified. These practices were then defined and the theoretical processes by which these practices were suspected to improve human safety performance in organizations were articulated. Because the premise behind S&H-specific management practices is to equip the employees with relevant safety knowledge, skills, abilities and motivation, it was argued that they align nicely with the theory and literature related to high-performance work practices and are in fact a specific form of them. These practices were titled safety-and-health-specific high-performance work practices (S&H-HPWPs) and their association with collective levels of task and team safety behaviors and objective safety performance was subsequently tested.

Through this analysis, it was found that task and team safety behaviors, adapted from Griffin, et al. (2007), mediated the relationship between S&H-HPWPs and objective injury and illnesses statistics. This finding is consistent with the theoretical argument that HPWPs can influence organizational performance through

Path	B	β	z	p	R^2
Task Safety Proficiency←S&H-HPWP	.04	.55	5.49	<.01	.33
Team Safety Proficiency←S&H-HPWP	.03	.52	4.81	<.01	.28
Recordable Accidents←Task Safety Proficiency	-.13	-.28	-2.10	.03	.40
Recordable Accidents←Team Safety Proficiency	-.24	-.37	-2.80	<.01	
Lost-Time Accidents←Task Safety Proficiency	-.06	-.20	-1.33	.18	.41
Lost-Time Accidents←Team Safety Proficiency	-.13	-.45	-3.11	<.01	

Note: S&H-HPWP: system of safety and health-specific high performance work practices; B is the unstandardized regression coefficient; β is the standardized regression coefficient; Z is the value of the z test statistic for the regression coefficient; p is the significance level for the regression coefficient; R^2 is the amount of variance explained in the construct by the predictors with a predictive pathway leading to the construct.

Table 2 Conceptual model parameter estimates

	Outcomes	
Relationship	OSHA Recordable Accidents	Lost Time Accidents
Total	-.414*	-.390*
Direct	-.047	-.009
Indirect	-.378*	-.381*

Note: *estimates significant at the $p < .001$ level.

Table 3 Standardized direct and indirect effects based on independent construct (system of S&H-HPWP) on target constructs (recordable and lost-time accidents) through mediating constructs (task and team-related safety proficiency)

changes in an organization's internal social structure (Evans & Davis, 2005). Notably the argument that safety behaviors mediate the relationship between safety management practices and occupational injuries is not a novel one (see the meta-analysis conducted by Christian, Bradley, Wallace & Burke, 2009). However, these findings suggest that the socially directed forms of safety behavior, operationalized in the current study as team safety proficiency, can be a more powerful predictor of collective levels of safety performance in an interdependent context.

Limitations are associated with this empirical effort. Although the hypotheses were developed through a logic of casual order, consistent with other cross-section research designs, causality cannot be explicitly claimed. Further, because the research design used group statistics rather than individual-level observations, the resulting empirical power was less than optimal resulting in inconclusive results regarding the effectiveness of four of the individual S&H-HPWPs (i.e., nonsignificant correlation coefficients between the safety behavior constructs and the individual S&H-HPWPs of safe task assignment, accident investigation, safety training, and hiring for safety).

Given these noted limitations, the findings of this empirical effort support the premise that, in an interdependent context, key organizational outcomes (such as group safety performance) can be most efficiently achieved through helping and cooperative-type behaviors between workers (Griffin, et al., 2007). In an interdependent context organizations not only need to develop the competencies that govern individual task proficiency, but must also facilitate behavioral, as well as verbal and cognitive, cooperation between coworkers (Marks, Mathieu & Zaccaro, 2001). For a worker in high-hazard contexts, team proficiency behaviors might include the exchange of safety-related information, open communication and coordination of tasks and helping coworkers complete physically or mentally demanding tasks.

The results of this analysis are relevant to both practitioners and researchers. S&H-HPWPs offer an approach to human-performance-focused safety management that facilitate both task and team safety behavior, both of which have been identified as critical in an interdependent work context. Both task and team safety performance were predicted by S&H-HPWPs and significantly (negatively) predicted injuries and illnesses in the sample. Thus, the unitary system of S&H-HPWPs represents a valuable tool that can be used use to improve organizational safety performance through human safety performance. S&H-HPWPs represent a much-needed human performance approach to accident prevention in organizations that can be utilized as a focal point in building, improving or maintaining an effective workplace safety program. Finally, S&H-HPWPs offer rich prospects for future theoretical and empirical development. ✪

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Appendix A: List of items used to measure each S&H management practice

Employee Involvement

•Employees are involved in the process of creating safe work instructions.

•Employees can influence STOP work criteria.

•Employees are involved in devising solutions to incidents that resulted from human error.

•Employees are involved in doing safety observations of other employees.

•Employees are involved in conducting accident investigations.

•Employees are involved in the hiring for safety of their peers.

Pre- & Posttask Safety Reviews

•How often are pretask safety reviews done (i.e., planning and reviewing the safety considerations of the task)? (Seven-point Likert scale, Never to Always)

•When pretask safety reviews are done, a review of critical steps is conducted.

•When pretask safety reviews are done, error likely steps / situations are addressed.

•When pretask safety reviews are done, the worst thing that could happen is discussed.

•When pretask safety reviews are done, special safe work procedures including PPE is discussed.

•When pretask safety reviews are done, energy sources requiring isolation are addressed.

•When pretask safety reviews are done, STOP work criteria are discussed.

•After finishing a task, employees participate in reviewing the safety aspects of their task.

Safe Work Procedures

•Percent of routine tasks that safe work safe work procedures have been developed for. (0%, 25%, 50%, 75%, or 100%).

•Percent of high-risk jobs that have hazard analyses completed for. (0%, 25%, 50%, 75%, or 100%).

•Hazard analyses previously performed are thorough and robust.

•Safe work safe work procedures are reviewed and updated when necessary.

•Safety "lessons learned" are considered when reviewing and updating safe work safe work procedures.

•Safe work safe work procedures contain a warning about the potential consequences of deviation.

Hiring for S&H

•The safety values and beliefs of this organization are discussed in the interviews with potential employees.

•Only the best people are hired to work in this organization.

•Number of interviews a job applicant goes through prior to a job offer. (0, 1, 2, 3, >3)

•Job applicants go through background checks. (Seven-point Likert scale, Never to Always)

•Job applicants have to pass a physical stating that they can physically do the job. (seven-point Likert scale, Never to Always)

•Job applicants undergo a drug test prior to being hired. (Seven-point Likert scale, Never to Always)

Cooperation Facilitation

•Employees are encouraged to cooperate with each other on resolving safety issues.

•Formal communication mechanisms among co-workers are robust enough to ensure that information being shared covers all necessary safety information.

•Formal mechanisms are utilized to ensure that key safety information is communicated between off-going and on-coming shifts.

S&H Training

•Throughout the course of the year, how often employees are formally trained on the safety aspects of their job. (Seven-point Likert scale, Never to Always)

•Number of hours of formal safety training. (<10, 11-20, >20) reverse coded

•Employee safety training incorporates elements of hazard recognition and avoidance.

Communication & Information Sharing

•Employees are informed of new or revised safety rules and safe work instructions.

•Employees are informed about potential hazards in the workplace or their tasks.

•Information about the importance of working safely is communicated to employees (e.g., print media, posters, payroll stuffers).

•Employees are informed about safety incidents experienced in other similar organizations.

•Employees are informed about safety incidents and or near misses experienced by other employees.

•When safety incidents do occur, the results of the investigation are shared among the workforce.

Accident Investigations

•Incident investigations seek to uncover potential reasons why human error might have contributed to the incident.

•How soon accidents are investigated. (<24 hours, 24 to 48 hours, >48 hours) reverse coded.

•Accident investigations are conducted by a team of individuals consisting of employee representative(s), a safety representative, and the injured employee's immediate supervisor.

Detection & Monitoring

•Safety checklists have been developed corresponding to possible workplace hazardous conditions.

•Safety checklists have been developed that correspond to possible workplace at risk behaviors.

•Safety observations target behaviors that deviate from safe work instructions.

•When employees break safe work rules, it can result in negative consequences for employees.

•Deviations from safe work instructions are tracked in monitored.

Safe Task Assignment

•Supervisors are provided with the flexibility to assign the right employee to the task.

•When flexibility is allowed, past experience with the task is considered.

•When flexibility is allowed, the physical demands of the task are considered.

•When flexibility is allowed, the risk of fatigue or extended work hours is considered.

•When flexibility is allowed, the risk associated with stress or distraction is considered.

Rethinking Workplace Health & Safety Training: Utilizing the Translanguaging Instructional Method to Reach Foreign-Born Construction Workers of Hispanic Origin

James R. Wilkins, Jondou C. Chen and James L. Jenkins

Abstract

Foreign-born workers of Hispanic origin currently employed in the U.S. construction industry account for a disproportionately high number of accidents and injuries compared to their American-born colleagues. Despite the fact that many of these workers have only limited fluency in spoken and written English, the safety training they receive is generally delivered in English only. A review of the literature addressing adult learning theory among bilingual learners was conducted and a study was then undertaken utilizing a randomized experimental design to measure knowledge-retention among trainees on a safety training course that modeled the OSHA 10-hour Construction Health and Safety Training Course. Trainees were assigned randomly to one of three groups, and training was delivered either in English only, Spanish only or in both English and Spanish through an instructional method known as translanguaging. Those whose training incorporated translanguaging scored the highest when examined on the extent of their knowledge retention. These results will be of value to managers in human resources, to trainers in the industrial workplace and to policy makers.

Keywords
safety, training, safety and health, Hispanic, adult learning, organizational learning

Introduction

Safety awareness among employees in the workplace remains a long-term concern for industry leaders working in construction. Although the industry is seeing a year-on-year reduction in the incidence of accidents and fatalities, partly on account of the implementation of modern vocational training methods, this trend is not universal, and workers belonging to certain minority demographics remain particularly at risk. The challenge for employers is to understand and appreciate both what does and what does not constitute effective vocational training and to implement innovative new schemes that cater specifically to the requirements of their workers. These requirements will differ from person to person and will be affected by each worker's individual socioeconomic and cultural situation. Understanding the role these factors play is vital to improving instructional practice in the future.

One particularly prominent minority demographic among construction workers in the U.S. comprises foreign-born workers of Hispanic origin, many of whom speak English as a second language with dramatically varying degrees of proficiency. It would be profoundly in the interests of this significant minority group to develop training courses that include a bilingual component. The construction industry employs a greater proportion of Hispanic workers than any other national industry, comprising 2.1 million Hispanic workers in 2010 making up 24.4% of the construction workforce (Bureau of Labor Statistics, 2011; U.S. Census Bureau, 2011). However, Hispanic workers have a 70% higher risk of sustaining work-related injuries (fatal or otherwise) than workers of non-Hispanic origin (CDC, 2008; Walter, 2008).

Recent years have seen substantial improvements in the provision of safety and health training across the industry, but relatively little has been done to address the specific needs of Hispanic workers born abroad. Wilkins (2009) surveyed participants in a 10-hour Construction Health and Safety Training Course and ascertained that only 14% were offered the training in a language other than English. Without wishing to denigrate the undoubted progress being made in training provision across the industry, it is apparent that more can and should be done to take account of the cultural diversity of construction workers and tailor instructional methodologies to meet their respective needs.

Purpose of the Study

The overall purpose of this study was to identify how well foreign-born construction workers of Hispanic origin in New York City would perform on a posttest that they undertook following a training course that closely resembled

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the OSHA10-hour Construction Health and Safety Training Course. The intention was to ascertain whether scores varied depending on whether the course was delivered in English or Spanish or through translanguaging, whereby the instructions and resources were presented in both English and Spanish. The researchers believed that if the groups that underwent Spanish-only instruction or training that utilized the translanguaging method presented higher posttest scores, then this would represent strong evidence that the current approach does not serve foreign-born workers of Hispanic origin as well as it could.

At present, OSHA (2013) Outreach Training Program requires that "outreach trainers must teach students in a language that they understand." The program requirements also indicate that when trainees' vocabularies are limited, then the trainer must account for that limitation. The document mentions the use of a translator when training nonfluent English speakers, but specifies that it must take twice as long to conduct the training in order to account for the role of the translator who, essentially, must repeat every word spoken by an authorized trainer. This present study was designed to discover whether training offered in Spanish or through a translanguaging approach would be equally effective, thereby eliminating the need for a translator and reducing the overall time burden and expense associated with safety and health training.

The current OSHA guidelines requiring that trainees be instructed in a language in which they are fluent and literate are valuable and important; however, in a globalized economy, such a regulation fails to account for the workers who lack *technical fluency* in either English or Spanish. This is true, for example, of native Spanish speakers who are nevertheless familiar only with English technical vocabulary and specialized language associated with their place of work. Such trainees are culturally fluent, however, with the practice of moving easily from one language to another. Rather than penalize them for this capacity, translanguaging takes advantage of it by delivering material efficiently for those with a specialized degree of bilingual ability.

Brunette (2005) asserted the need for linguistically and culturally appropriate tuition designed to take into account endemic diversity within the construction workforce. Brunette went on to state that the mere practice of translation is insufficient if the desired result is to improve knowledge retention, since translation alone does little to address issues of diversity. He presented a lengthy set of guidelines for making training more accessible for Spanish-speaking workers, but failed to address in detail the high level of diversity among Spanish-speaking construction workers as a whole. The present study is more targeted, limiting its attention to foreign-born workers of Hispanic origin who are now living and working in the U.S.

Research Question

Would there be a statistically significant improvement in the posttest scores of participants if a training program that simulated the OSHA 10-hour Construction Health and Safety Training Course was taught through the use of translanguaging, rather than exclusively either in English-only or Spanish-only formats?

Hypothesis

When completing the posttest, foreign-born workers of Hispanic origin would achieve a higher score if they completed the training course when the language of instruction was Spanish, whereas those who were taught using translanguaging or in English only would perform less well.

Conceptual Framework

Although the themes covered by this study were abstract and universal, the practical applications for this research were specific. The study was designed based on rationality. Blank and Slipp (1994) correctly observed that immigrants from non-English-speaking nations were typically most comfortable in their new host nations when conversing in their arterial language. They do not, however, rely exclusively on this, and are typically keen to learn and depend upon conversational English for interacting with others. It is apparent that literacy levels in both English and Spanish vary considerably among foreign-born construction workers of Hispanic origin. Although the evidence suggests that employers are taking steps to provide training materials in Spanish as well as English, there is still little sign of a comprehensive and coherent bilingual approach to safety and health training that might have a significant reductive effect on the instances of accidents and fatalities within this demographic.

The most effective training is designed to suit the specific requirements of learners and one tool for measuring this is the posttest. Comparing the scores achieved by those who received their instructions in English, Spanish or through the instructional method of translanguaging allowed researchers to determine which approach was more effective in terms of knowledge retention and understanding. The more effective the method, the less likely the learner would become the victim of an avoidable workplace incident once the training course was complete and, therefore, more lives could be saved on account of a more responsive approach to training and instruction.

Literature Review

While the workplace safety risks faced by foreign-born construction workers of Hispanic origin are not necessarily unique, the demographic shift in the labor force necessitates novel approaches to safety training (Moran & Petsod, 2003; Wilkins, 2011). These changes are especially apparent in construction workers younger than age 30. Only 23% of non-Hispanic construction workers are under age 30 whereas 38% of Hispanic workers fall into that age bracket. As the construction industry comes to rely more heavily on Hispanic immigrants, issues of cultural insensitivity and nonfluency in English will lead to a reverse in the current decline in incidences of workplace injury and fatality. Citing the example of Pferd Milwaukee Brush (PMB), the authors (2003) made the case for employers investing much more heavily in worker training, with a particular focus on those affected by their immigration status.

At the same time, illiteracy and lack of educational attainment are significant concerns within this workforce and have

evidently not been properly addressed by the schooling system – here or abroad (Center for Construction Research and Training, 2007; Crowley & Lutz, 1997). With little help from the federal government, the burden for closing this gap falls to employers (Zehr, 2011). This perspective is supported by research conducted in Canada, which identified the development of communication skills and intercultural competency as being among the key requirements for any adult training program for immigrant workers (Colleges Ontario, 2009). Again, the emphasis was on actual, not apparent comprehension and integration. The need to train employers to use different methodologies when instructing immigrant workers was also addressed. Suchite (2011) went further, arguing that the same pressures and challenges faced by the Hispanic immigrant workforce also exist in schools and higher education institutions and that a comparable methodology must be employed at that level which takes these into account.

Hispanic employment in construction increased from 1.9 million to 3.2 million between 2003 and 2007 (Pew Hispanic Center, 2007). The scale on which these workers are disproportionately affected by workplace accidents is, therefore, ever more apparent. Lavy, Aggarwal and Porwal (2010) cited illiteracy, language barriers and cultural differences as the key factors responsible for the higher incidence of injury within this demographic. Kagerer and Gandarilla (2011), responding to this observation, recommended that instructors distinguish between their domestic and immigrant trainees, recognizing, for instance, a cultural unwillingness among Mexican workers to admit to not understanding the training materials they receive.

This theme appears also in the work of Roelofs, Sprague-Martinez, Brunette and Azaroff (2011), in which a culture of intimidation endemic to certain work sites is identified with an unwillingness among workers to admit to not understanding safety instructions. Although such reticence is also observable in workers born in the U.S., the study found it to be particularly pronounced among immigrants. Canales, et al. (2009) supplemented these data with the recommendation that instructors responsible for training immigrant workers should themselves be of multicultural extraction or be familiar with a range of cultures, languages and social groupings.

Organizational Learning for Adults

Transformative learning experiences, critical to integrating those familiar with foreign educational systems into the American mainstream, were investigated by Giles and Alderson (2008), who emphasized the importance of creating learning environments within which all learners felt a sense of inclusion and mutual respect. Approaches to adult learning in the context of safety training were studied by Galbraith and Fouch (2007), who identified three applicable principles of andragogy: needs assessment; safety of the environment with regard to learners feeling comfortable and confident in expressing their thoughts; and the relationship between the trainer and the trainees. In the case of immigrant adult learners, cultural sympathy is a necessary foundation to support all three principles. Martinez and Wang (2006) reported a 46% wage differential between those immigrant workers who are proficient in English and those who are not.

Wrigley, et al. (2009) were right to draw attention to the disparity between fluency in spoken English and confidence in reading and writing. From a safety training perspective, it may be that what an instructor says is clear, but the written supporting materials are not or vice versa. Proctor and Silverman (2011), who approached the problem from a different perspective, nonetheless concur in observing the need for an instructional methodology that accounts both for biliteracy and translanguaging among immigrant workers, and Pray and Jimenez (2009) expressed various thoughts as to how this might best be implemented, although they only drew very general conclusions.

Second Language Acquisition: Translanguaging & Code-Switching

According to García (2009), translanguaging takes into account the different ways in which significant meanings are created through the use of more than one language in the learning environment. Translanguaging improves the direct communication experience, but also allows speakers to make deeper connections by associating content with preexisting knowledge in any language. The values of a translanguaging culture were expounded by Hornberger and Link (2012), who argued that the ideal scenario was one in which all workers utilized translanguaging to some degree. While difficult to dispute in principle, the article offered scant indication of how this was to be achieved. In the short term, therefore, the focus must remain on achieving cross-cultural fluency for trainers and trainees alike, minimizing the risk of miscommunication once trainees are situated within a working professional environment.

The positive impact of an instructional practice which recognizes the value of translanguaging was explored by Adamson and Fujimoto-Adamson (2012), whose conclusions were directly relevant to this present study. They argued that "many students and all mentors . . . see translanguaging as a means to create a learning space in which safe language practice can take place, especially for those less confident or motivated to conform to an 'English-only' policy" (Martin, 2003, p. 80; Savin-Baden, 2008). The relevance of this conclusion for the construction sector is clear from the numerous studies cited above which recognize the risk of alienating foreign-born workers within a still primarily English-speaking industry.

In an unrelated study, which nonetheless addressed the importance of language barriers within immigrant communities, Morales, Yakushko and Castro (2011) examined specifically the case of several Mexican-immigrant families in the Midwest, observing the importance of translanguaging in upbringings and the phenomenon of language brokering within families. While recognizing the value of speaking several languages fluently, the study strongly suggested that where one language is dominant, or instruction is not available in both, miscommunication becomes the norm and relationships suffer. Outside the family unit, a similar conclusion may be applied to disaffected workers who struggle to engage in the training process precisely because they feel disenfranchised on account of the monolingual instruction they receive. This phenomenon

is ever more significant in the field of construction, as the number of foreign-born workers of Hispanic origin increases.

Common Misconceptions Regarding Users of Translanguaging

Harper and de Jong (2004) commented that "in many introductory English as a Second Language (ESL) workshops outside of the translanguaging profession, the tendency is to over-simplify theory thereby over-emphasizing overlap between first and second language learning" (p. 153). There is, therefore, a tendency not to appreciate the sometimes nuanced distinction between fluency and a working knowledge of a second language. Where the first all but guarantees understanding in a training scenario, the second may well not.

In workplace learning environments, when foreign-born workers of Hispanic origin are explicitly denied translanguaging opportunities, they simply do not participate fully in any training regimen. It takes 2 to 3 years to become proficient in basic communication skills in a second language and 4 to 10 years to attain competence in second language academic skills (Lucas & Katz, 1994). Furthermore, if nonnative English speakers are immersed in their second language to the exclusion of their arterial language, they will not have access to the content area knowledge and academic skills that their English-speaking peers are developing. This may result in learners falling further behind.

Summary

The critical literature cited here supports the thesis that miscommunication, one cause of avoidable accidents in the workplace, derives from cultural misunderstanding, language barriers and a lack of sympathy between trainers and their trainees. Addressing all three deficiencies is the most effective course toward shaping a new instructional methodology designed specifically to enfranchise foreign-born construction workers of Hispanic origin. The role played by translanguaging, biliteracy classes and andragogy in this case is likely to be significant, as these are the recurring themes within this body of critical literature. The consensus appears to be that no existing form of instruction is functioning effectively, and that although the content of the OSHA training courses is, of itself, sufficient to improve workplace safety, the instructional methods currently used to deliver this content still leave much to be desired.

Method

Research Design

A static group comparison design was utilized for the study. The method was adapted to accommodate two experimental groups and one control group. The control group comprised randomly assigned participants who underwent the training program in an English-only format (English-only Group). This group was considered the control group because it modeled an ordinary workplace education situation in which training was offered in an English-only format, even when the training program was attended by foreign-born workers of Hispanic origin with varying levels of English language fluency. The two experimental groups included randomly-assigned participants who underwent training in a Spanish-only format (Spanish-only Group) and those who were trained using translanguaging (Translanguaging Group). Researchers utilized a classic double-blinded technique in the study to reduce the likelihood of demand characteristics such as Hawthorne or Rosenthal effects. That is, neither trainer nor participants were likely to modify their behavior or performance given that they were unaware of the ongoing research project and hypothesis being tested (Neuman, 2012).

Population & Recruitment

U.S. Census Bureau (n.d.) reported that 35,853 individuals of Hispanic descent were working in construction in the New York City metropolitan area during the 2011 fiscal year. While it is recognized that not all immigrants in construction are Hispanic and that not all Hispanics are immigrants, this figure of 35,853 will serve as a strict upper-bound estimate for the number of foreign-born workers of Hispanic origin.

Flyers were placed at construction sites around all five boroughs of New York City and circulated to organizations that represent Hispanic construction workers and safety and health professionals. The researcher also used various social networking outlets to offer free training to eligible Latinos employed in construction. In each recruitment effort, the researchers offered to provide free 10-hour safety and health training to Hispanic construction personnel who had not previously completed a 10-hour or 30-hour OSHA Construction Health and Safety Training Course. Those interested in being considered were directed to a URL to register and complete an integrated digital consent form specifying their willingness to participate in a study appertaining to the evaluation of workplace training.

The online form was designed to be extremely user-friendly and was made available in both English and Spanish. The form provided an area where registrants could provide contact details and another area for them to answer qualification questions.

Sample

Participants included foreign-born construction workers of Hispanic origin who researchers recruited to comprise a convenience sample. *A priori* sample size calculations utilized the previously reported population size and held that a 5% margin of error, a 95% confidence level and a 50% response distribution would be acceptable. With three groups and assuming random effects for each treatment, the suggested sample size was set at 572 with power level .9844. Post hoc analysis validated these statistical assumptions given group differences of 11.2% or larger for the primary outcome variable and a 62% response distribution.

Flyers and e-mails were directed to construction workplaces and organizations that represent Hispanic construction workers. The flyers detailed an opportunity for Hispanic construction laborers to receive free vocational safety training. Interested individuals were directed to a URL, by means of which they could express their interest and register for the training. The electronic

screening instrument included questions asking participants if they self-identified as Hispanic, spoke some Spanish, spoke some English, and if they had ever completed a 10-hour or 30-hour OSHA Construction Health and Safety Training Course. Participants were also requested to identify their country of birth and the number of years that they had worked in the construction industry in the U.S. Initial respondents were excluded if they did not identify as Hispanic, were not born in a Latin American country, spoke no English or Spanish, or if they had previously completed a 10-hour or 30-hour OSHA Construction Health and Safety Training Course.

The recruitment URL was accessed by 1,217 unique individuals with 819 respondents deemed eligible to participate in the study after exclusion criteria were applied. Of the eligible respondents, only 703 registrations were completed and logged. The names and contact details for each respondent were electronically randomized and sorted according to the treatment group to which they were attached. Training times and dates were established, and respondents were contacted and invited to participate in training alongside other members of the treatment group to which they were randomly assigned. Researchers were careful not to mention language of instruction and were intentionally vague when asked about this by participants. Some respondents were unavailable to participate in the training program due to preexisting obligations, and some chose not to participate, having lost interest postselection. In total, 621 participants were confirmed.

Trainer Characteristics

The trainer recruited for the study was a foreign-born native speaker of the Spanish language from a Latin American nation. He had more than 5 years of on-site construction experience in Latin America and held a recognized baccalaureate degree in civil engineering. Following his arrival in the U.S., he undertook further studies and graduated with a master's degree in Construction Management. During his studies, he worked as an on-site safety coordinator for a large construction corporation based in New York. At the time of the study, the trainer held a certified safety professional (CSP) designation and was authorized through OSHA's Outreach Training Program to conduct construction safety training in the U.S.

Trainer's language proficiency. To demonstrate his proficiency in English, the trainer presented scores from the Test of English as a Foreign Language that was administered in 2009 by the world-recognized Educational Testing Service (ETS). The scores were divided into four scaled sections: *reading, listening, speaking and writing*. The maximum achievable score on each section was 30. The listening and speaking scores for the selected trainer were 26 and 28, respectively.

According to the ETS, the scores indicate a high level of proficiency in listening and a good level of proficiency in speaking. "Good" was the highest achievable level for the speaking section and "high" was the highest achievable level for the listening section. Specific scores for the other sections were not germane to this study; however, the trainer had scored at the highest levels in both reading and writing. Employing the self-assessment provided by the Interagency Language Roundtable scale for speaking and listening in the Spanish language, the trainer was deemed to have ILR Level 5 proficiency in each section; this meant that the trainer had mastered the English language with native fluency (Interagency Language Roundtable, 2012).

Posttest measure. To evaluate participants' understanding of workplace safety, the trainer had participants take a test immediately following the training sessions. The posttest utilized was adapted from a study that sought to measure construction-specific safety and health knowledge of construction workers across the U.S. "The questions were clustered based on face validity" (Wilkins, 2009, p. 65). The measure comprised questions from each of the major designated topics required to be covered in a standard OSHA 10-hour Construction Health and Safety Training Course. Those designated topics were covered during the simulated training utilized in this course and included introduction to OSHA, fall protection, electrical, struck by, caught in/between and personal protective and lifesaving equipment. For the introduction to OSHA section of the posttest, trainees were asked to respond to ten multiple-choice questions. For every other section, five multiple-choice questions were presented. The larger number of questions in the first section of the test reflected the quantity of instructional material that was covered in that portion of the training.

Results

Demographics

The sample (n = 621) comprised construction workers who identified as Hispanic and were born in countries in Latin America. All participants reported varying degrees of fluency in both English and Spanish, and indicated that they had never completed an OSHA 10- or 30-hour Construction Health and Safety Training course on any previous occasion. Participants reported a mean of just fewer than 15 (M = 14.95, SD = 7.28) years working in the U.S. construction industry. Subjects were drawn from a total of 13 Latin American countries, with no fewer than 15 participants (Paraguay) and no more than 106 (Dominican Republic) coming from any one country, such that each country represented between 2.4% and 17.1% of the overall sample. In addition to the Dominican Republic, participants were more likely to come from Colombia (96), Ecuador (79) and Mexico (60), with these four countries accounting for the origins of 54.9% of the sample.

Posttest Results

By treatment group. Across all groups, participants correctly answered an average of 20.62 (SD = 4.74) out of 33 questions correctly, or 62.5%, on the safety posttest. Participants in the English-only group scored an average of 16.70 (SD = 3.92) correct answers, or 50.6%; participants in the Spanish-only group scored an average of 20.41 (SD = 3.76) correct answers, or 61.8%; and participants in the translanguaging group scored an average of 24.76 (SD = 2.30), or 75.0%. Group differences were significant (F(2, 618) =

	Frequency	Percent
Country of Origin		
Chile	34	5.5
Colombia	96	15.5
Costa Rica	17	2.7
Cuba	34	5.5
Dominican Republic	106	17.1
Ecuador	79	12.7
Honduras	44	7.1
Mexico	60	9.7
Panama	37	6.0
Paraguay	15	2.4
Peru	43	6.9
Uruguay	21	3.4
Venezuela	35	5.6
Treatment Group		
English Only	207	33.3
Spanish Only	207	33.3
Translanguaging	207	33.3
Total	621	100.0

Table 1 Descriptive frequencies and percentages

291.381, $p < .001$) with participants belonging to the translanguaging group scoring 13.2% higher than those in the Spanish-only group and 24.4% higher than those in the English-only group. Members of the Spanish-only group scored, on average, 11.2% higher than members of the English-only group.

These group differences remained consistent across all six subsections of the safety quiz with between-group differences ranging from 3.2% to 33.2%. Participants in the translanguaging group did better than participants in the Spanish-only group by an average of 12.0% per subsection, with between-group differences ranging from 7.8% to 14.6%. Participants in the translanguaging group also outperformed participants in the English-only group by an even larger margin of 22.1% on average per subsection, with between-group differences ranging from 17.1% to 25.3%.

Participants in the Spanish-only group scored on average 10.1% higher per subsection than participants in the English only group with group differences ranging from 3.2% to 14.8%. All between-group subsection differences were significant at $p < .01$ with the exception of margin between the Spanish- and English-only groups on the personal protective equipment subsection (61.9% to 58.6%, $t(412) = -1.156$, $p = .248$).

It is significant to note that participants' scores for all subsections significantly correlated with their overall scores for the safety posttest at $p < .01$ with correlation coefficients ranging from .420 to .663. Participants' scores for each subsection were also, by and large, significantly associated with one another, with the exception of the subsection entitled "personal protective equipment" not being significantly associated either with the "fall protection" subsection or the "struck by" subsection. Correlation coefficients between subsections were considerably smaller than between the subsections and overall scores, however, with values ranging between .035 and .220, thus providing evidence of the discriminant (divergent) validity of the subsections in comparison to one another.

By years of experience. Participants' self-reported years of experience working in the field of construction in the U.S. was not a factor significantly associated with their overall safety posttest score or with their scores on any of the subsections thereof. Correlation coefficients here ranged from -.078 for the "electrical" subsection to .060 for the "caught in/between" subsection, with three slightly negative and three slightly positive correlations. When testing for correlations between years of experience within each treatment group, only one marginally significant association was found with years of experience negatively predicting the score on the "electrical" subsection for participants in the Spanish-only group ($r = -.166$, $p = .017$). This finding should be treated with extreme caution, however, given that this p value becomes non-significant when utilizing a Bonferroni correction, assuming three or more hypotheses are being tested.

By country of origin. Participants' overall safety posttest scores did vary significantly in relation to self-reported country of origin ($F(12, 608) = 4.097$, $p < .001$), with average scores ranging from 18, or 54.5%, for Cuba to 26.2, or 79.5%, for Costa Rica. The only country of origin that varied significantly

Posttest Section	Language of Instruction	Mean	SD	N	SE
Overall	All	62.49	14.35	621	.58
	English only	50.59	11.88	207	.83
	Spanish only	61.84	11.38	207	.79
	Translanguaging	75.04	6.96	207	.48
Intro	All	41.40	19.62	621	.79
	English only	29.56	17.97	207	1.25
	Spanish only	40.93	17.53	207	1.22
	Translanguaging	53.71	15.32	207	1.07
FP	All	62.74	27.70	621	1.11
	English only	49.66	28.34	207	1.97
	Spanish only	64.44	26.21	207	1.82
	Translanguaging	74.11	22.69	207	1.58
Electrical	All	65.28	29.01	621	1.16
	English only	52.75	30.52	207	2.12
	Spanish only	65.02	28.45	207	1.98
	Translanguaging	78.07	21.68	207	1.51
Struck By	All	65.73	26.41	621	1.06
	English only	56.62	28.86	207	2.01
	Spanish only	66.38	24.25	207	1.69
	Translanguaging	74.20	22.84	207	1.59
Caught In	All	62.19	27.34	621	1.10
	English only	51.21	26.77	207	1.86
	Spanish only	60.39	27.45	207	1.91
	Translanguaging	74.98	22.16	207	1.54
PPE	All	65.41	27.53	621	1.10
	English only	58.65	30.24	207	2.10
	Spanish only	61.84	25.67	207	1.78
	Translanguaging	75.75	23.26	207	1.62

Table 2 Scores (percentage correct) on posttraining test, by language of instruction group

from all other countries, however, was Costa Rica. Participants of Costa Rican origin scored 17% higher than the average score across the sample and 14.3% higher than participants from the next closest country, Chile.

Looking at between-treatment group differences by country the statistical differences are significant ($p < .05$) in every country and follow the same pattern as described at the overall sample level. Participants in the translanguaging group scored higher than participants in the Spanish-only group who, in turn, scored higher than participants in the English-only group.

Overall. The overall ANCOVA model including treatment group, years of experience and country of origin was significant and accounted for 54.1% of the variance in safety posttest scores. Controlling for other variables, treatment group remained a significant predictor of safety posttest score with participants in the translanguaging group scoring 15.9% higher than participants in the Spanish-only group and 25.2% higher than participants in the English-only group. Years of experience remained non-significant ($F(1, 581) = .110$, $p = .740$), whereas country of origin remained significant ($F(12, 581) = 78.847$, $p < .001$), although this result was affected by higher scores among Costa Rican participants. A treatment group by country of origin interaction term was found to be non-significant ($F(24, 581) = 7.550$, $p = .819$) indicating that results did not differ across countries within treatment group or vice versa. This is not surprising given our previously reported finding that between-group differences remained significant and consistent irrespective of country of origin.

Discussion

The results of this study provide a new and distinctive perspective on the case of foreign-born workers of Hispanic origin employed within the construction industry in the U.S.. That perspective represents the strongest and most comprehensive case to date for the institution of translanguaging as the instructional method of preference among safety trainers in this field. Although translanguaging is a method already used in K-12 educational contexts, it is less frequently applied to the tuition of adult learners, and the results presented here suggest that this omission currently represents a grave oversight on the

	1.	2.	3.	4.	5.	6.	7.	8.
1. Intro	1	.174**	.220**	.135**	.089*	.091*	.663**	.014
2. Fall protection	.174**	1	.113**	.084*	.142**	.035	.481**	.002
3. Electrical	.220**	.113**	1	.120**	.138**	.085*	.538**	-.078
4. Struck by	.135**	.084*	.120**	1	.151**	.062	.463**	-.019
5. Caught in	.089*	.142**	.138**	.151**	1	.120**	.490**	.060
6. PPE	.091*	.035	.085*	.062	.120**	1	.420**	-.052
7. Overall score	.663**	.481**	.538**	.463**	.490**	.420**	1	-.020
8. Years' experience	.014	.002	-.078	-.019	.060	-.052	-.020	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 3 Correlations of posttest subsections and years of experience

part of vocational educators. A detailed review of the existing literature referring to adult learning in the industry revealed only one study that has previously examined the effectiveness of translanguaging—that research having been undertaken as a pilot study for this investigation, in which learners subjected to instruction through translanguaging scored higher than those instructed only in Spanish or English. More specifically, that pilot study revealed that participants trained through the instruction method of translanguaging scored 12.42% higher than those trained wholly in Spanish and 33.49% higher than those trained completely in English (Wilkins, Alibutod & Nugroho, 2013). The lack of curiosity previously shown by researchers should not detract from the fact that, now data is available, it clearly vindicates the case for integrating translanguaging into existing training programs for bilingual learners.

The specific focus of this study was to determine whether among the participants surveyed there was a statistically significant improvement in posttest scores among those educated using translanguaging compared to those taught in Spanish-only or English-only environments. When designing this study's research methodology, it was hypothesized that those taught exclusively in Spanish would demonstrate the greatest knowledge retention, and so achieve the highest scores on their tests. This assumption was made on the basis that those learners surveyed spoke Spanish as their arterial language and had varying levels of fluency in English. The results of the experiment undermined this hypothesis, however, following instead the trend identified in the previous pilot study, in that those adult learners educated using translanguaging as an instructional methodology achieved higher scores overall on their tests, with the average score being 24.76 questions answered correctly, versus 20.41 in the Spanish-only group and only 16.70 in the English-only group. In answer to our initial inquiry, therefore, it seems apparent that training using translanguaging leads to a statistically significant improvement in knowledge-retention among trainees.

Among the strengths of the methodological design and delivery of this experimental study was the availability of a trainer who was fully bilingual. Additionally, by situating the research in New York City, it was possible to generate a positive response to the appeal for participants, since the community of foreign-born workers of Hispanic origin in the city is so large. Nevertheless, although this study did match predictions about the scale of participation, a more comprehensive study would have been possible with a wider sample size, especially given the sheer number of Hispanic workers active in the construction industry today, in whose interest this research is largely being conducted.

The intention behind conducting this study is to reform the culture of training within the industry to achieve practical improvements in the standard of safe working practice. It is important to note that there are currently too few Spanish-speaking construction-industry safety and health trainers available to accommodate the large and growing needs of this community and that many of their trainees suffer from low motivation to train on account of a cultural sense that their promotional prospects are limited because of the cultural and linguistic barriers they often face. Additionally, many workers are undocumented and obliged to work under the radar, thereby sometimes putting themselves at risk by electing to avoid costly safety training.

Clearly, the solution is to recruit more members of this community with bilingual fluency to become safety trainers, but the train-the-trainer courses available are costly and, therefore, prohibitive for many. It is important in this context to note the disparity between the wages earned by many Hispanic workers compared to those doing the same job but being of Caucasian ethnicity and often earning a higher hourly rate. All such disparities can contribute to demotivation among workers of Hispanic origin, and all will need to be addressed in order to bring the level of avoidable accidents under control. Part of the solution might be for the federal government, through the Department of Labor, to find ways to make the train-the-trainer courses more affordable and more appealing to members of this demographic. Perhaps the training on this course should take place in Spanish, or use translanguaging, much like the 10- and 30-hour training courses themselves.

This study also draws attention to the wider possible applications for translanguaging across the fields of adult learning and vocational education. Although the focus of this research was the construction industry, there is no reason to suppose that similar benefits could not be drawn by applying the same methodology to training courses in manufacturing, transport and other industries where the standard of spoken English is variable and large minority groups make up a significant component of the workforce. Evidently, there is significant scope for conducting further studies to determine how widespread and universal the value of translanguaging can be.

It would also be valuable to maintain contact with those surveyed over a period of time and attempt to evaluate the incidence of accidents and injuries among those from the three groups (Spanish-only, English-only and Translanguaging) in order to gather verifiable data to further support the value of translanguaging as a tool for saving lives and improving the prospects of otherwise marginalized workers who do their jobs effectively, despite existing linguistic barriers. ✪

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Characterization of Airborne Concentrations of MDI During Simulated Consumer Use of Gorilla Glue®

Kim E. Anderson and Michael J. McCoy

Abstract

Methylene bisphenyl isocyanate (MDI) is one of several isocyanates used in a variety of consumer products. An expandable polyurethane adhesive, Gorilla Glue® (Gorilla Glue), contains a mixture of polymeric and monomeric MDI and is designed as a waterproof adhesive for consumer use. The objective of this study was to measure the airborne MDI vapor or aerosol concentrations and related potential exposure when MDI- and polymeric MDI (PMDI)-based Gorilla Glue are manually applied by a consumer. A work practice simulation study using Gorilla Glue, while quantitatively evaluating airborne concentrations of MDI during standard and hypothetical maximal worst-case consumer use, was conducted. Laboratory analysis for monomeric MDI and PMDI (oligomeric) revealed airborne concentrations below the limit of analytical detection of 0.0005 milligrams of MDI per cubic meter of air (mg/m3) during standard and worst-case uses of Gorilla Glue. Increasing the mass of glue, the time when the entire surface area of the glue was exposed to ambient conditions prior to clamping of the material being glued, and the surface area to which the glue was applied (furring strips and plywood) did not raise airborne MDI concentrations above the analytical limit of detection. It can be concluded that airborne concentrations will not likely exceed applicable occupational exposure limits (OELs) during the use of Gorilla Glue under the conditions presented in this study.

Keywords
isocyanates, adhesive, methylene bisphenyl isocyanate (MDI), inhalation

Introduction

Isocyanates are a group of highly reactive, low molecular weight, organic aromatic and aliphatic compounds. The distinguishing N=C=O (NCO) functional group is common to all isocyanate compounds. The organic aromatic compound MDI has several chemical synonyms, including methylene bisphenyl isocyanate, diphenylmethane 4,4'-diisocyanate and 4,4'-methylenediphenyl diisocyanate. Isocyanates readily react with compounds with active hydrogen atoms or nucleophiles. Representative nucleophiles include water, alcohols and amines. Generally, polyurethane polymer is formed when an isocyanate is reacted with a poly alcohol or polyol. Isocyanates are often sequentially reacted via polymerization to form polyisocyanates, such as PMDI.

Prior to the 1980s, toluene diisocyanate (TDI) was the most commonly utilized isocyanate in the manufacturing of a variety of polyurethane products. However, due to TDI's high volatility in comparison to other isocyanates, the use of MDI has surpassed the use of TDI in recent years. The two primary chemical compositions of MDI used in research, industrial and commercial applications are monomeric MDI and PMDI (Booth, Cummings, Karoly, et al., 2009). The monomeric form of MDI is essentially composed of the isomer 4,4'-methylenediphenyl diisocyanate, while small amounts of other MDI isomers may also be present. Monomeric MDI is a white to yellow, waxy solid at room temperature (Booth, et al., 2009). Monomeric MDI has a very low vapor pressure of 6.2×10^{-4} Pascal (Pa), while PMDI has a vapor pressure essentially one-half of monomeric MDI of 3.1×10^{-4} Pa (Booth, et al., 2009). Monomeric MDI is soluble in octane, benzene and kerosene and minimally soluble (0.2%) in water (Institute for Health and Consumer Protection, n.d.). PMDI is generally composed of a mixture of 50% MDI and 50% higher molecular weight oligomers of MDI (Booth, et al., 2009). At room temperature, PMDI is an amber- to brown-colored, viscous liquid (Booth, et al., 2009).

According to the most recent European Union Risk Assessment Report regarding MDI, in 1996, the worldwide production of all types of MDI was 2.5 million metric tons per year and the production of MDI was expected to continue to increase in the future (Institute for Health and Consumer Protection, n.d.). The majority of the world's MDI is used in the manufacture of polyurethane products, specifically uncured polyurethane spray foam and expandable foam. Polyurethane foam is manufactured in both flexible and rigid forms and

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can be found in cured form in numerous consumer products ranging from mattresses, home thermal insulation, Spandex™, automobile furnishings, furniture, footwear, boats, surfboards, packaging, golf balls and carpet underlayments (Booth, et al., 2009; Krone & Klingner, 2005). Polyurethane is also present in adhesives, coatings, binders, sealants and other chemical products (Booth, et al., 2009). MDI and PMDI are also used in a variety of one- and two-component polyurethane adhesives, which are poured, rolled, or cast for a variety of purposes. In 2004, 385 metric tons of monomeric MDI were used to make adhesives in the U.S., representing 10% of the total use of monomeric MDI nationally that year. Additionally, approximately 13,607 metric tons of polymeric monomers were used in the manufacture of all forms of adhesives in the U.S., representing 1.5% of the national use of PMDI in the U.S. in 2004 (Booth, et al., 2009).

Many different cured and uncured polyurethane products are on the market. Gorilla Glue is an example of an uncured, one-component, polyurethane adhesive containing a mixture of monomeric MDI and PMDI, which is designed and marketed as a waterproof adhesive for consumer use. The use and chemistry of Gorilla Glue is materially different than materials containing isocyanates that are applied by spray processes. This paper provides a review of the uses, occupational exposure limits and toxicity of MDI, and provides the results of an inhalational exposure study of Gorilla Glue during typical consumer use, as well as the hypothetical maximal worst-case potential during its unrealistic use.

Regulatory & Consensus Occupational Exposure Limits for MDI

Several regulatory and consensus occupational exposure limits (OELs) exist for MDI due to its occupational health sequelae, which are described later in this paper. OSHA (n.d.) has promulgated a ceiling limit for MDI of 0.2 mg/m^3 or 0.020 parts of MDI per million parts of air (ppm). OSHA's ceiling limit is the airborne concentration that shall not be exceeded at any time during a work day. American Conference of Governmental Industrial Hygienists (ACGIH; 2001) has established an 8-hour time-weighted average (TWA) threshold limit value (TLV) for MDI of 0.051 mg/m^3 or 0.005 ppm. NIOSH (2007) recommended exposure limit (REL) for MDI is 0.05 mg/m^3 or 0.005 ppm for up to a 10-hour TWA workday, and the NIOSH ceiling limit is 0.2 mg/m^3 or 0.02 ppm. The NIOSH ceiling limit is defined as the airborne concentration that shall not be exceeded during any part of the workday.

Since instantaneous monitoring for MDI is not feasible, NIOSH has recommended that the ceiling airborne concentration is assessed during a 15-minute exposure time period that shall not be exceeded at any time during a workday. The German Maximum Concentration Values in the Workplace (MAKs) for MDI are 0.05 mg/m^3 for an eight-hour TWA, and a 0.1 mg/m^3 ceiling limit concentration. The MAKs for MDI lists the "skin" and "sah" notations indicating that exposure to MDI include the potential for cutaneous absorption and of the potential for sensitization of the skin and airways, respectively. The authors were unable to identify any regulatory or consensus standards for PMDI. Generally, OELs represent the airborne concentration of MDI not expected to cause adverse health effects in nearly all workers during their working lifetime or other prescribed time periods, as applicable.

Occupational Airborne Exposures Utilizing Polyurethane-Based Adhesives

Polyurethane-based adhesives have significantly lower airborne exposure concentrations as compared to that of spray-applied polyurethane products. Vangronsveld, Berckmans, Verbinnen, et al. (2010) evaluated the use of MDI as an alternative to formaldehyde-based resins during the manufacture of composite wood products (CWP) in Belgium. The maximal geometric mean area airborne concentration of MDI from all area samples collected throughout the manufacturing facility was 0.0090 mg/m^3 (Vangronsveld, et al., 2010). It would be expected that airborne concentrations of MDI would be significantly higher in this environment as compared to airborne concentrations of MDI during Gorilla Glue application, as the volume and resulting surface area of Gorilla Glue adhesives during consumer use is significantly less than in this study. Nonetheless, the maximal geometric mean airborne MDI concentrations that were recorded in the Vangronsveld, et al. study were significantly lower than the relevant OELs for MDI.

In an evaluation of MDI-based polyurethane adhesives, Wirts and Salthammer (2002) compared one- and two-component adhesives to determine the concentrations of MDI vapor released during controlled laboratory conditions. One of the two-component adhesives was composed of a mixture of PMDI (5.4% 4,4'-MDI) and an undefined composition of bi- and tri-functional polyols. The second commercially available, two-component adhesive had as its primary ingredient PMDI a chemical of unknown composition. The one-component adhesive utilized a MDI pre-polymer resin (14.9% 4,4'-MDI). Wirts and Salthammer (2002) found that one-component adhesives polymerize more slowly and have higher area-specific emission rates of MDI, but did not measure or otherwise define the anticipated airborne MDI concentration that would be emitted during normal consumer use of a one-component adhesive under the intended use conditions.

Exposure to aerosolized MDI from the occupational use of polyurethane and other MDI-based adhesives was investigated by Booth, et al. (2009). In this study of nonconsumer uses of the MDI-based adhesives, 417 personal air samples that were collected from coating, adhesive, sealant and elastomer processes included end-use applications in electronics, construction, furniture, footwear, appliances and tires. Ultimately, 273 of the personal samples' airborne MDI concentrations were measured below the analytical laboratory's limit of quantification (LOQ) (Booth, et al., 2009).

One hundred eighteen samples had MDI concentrations which were less than the TLV, but above the LOQ. Thirteen personal air samples had MDI concentrations above the TLV, but less than the OSHA ceiling limit and 13 samples exceeded the OSHA ceiling limit. Of the samples that exceeded the

Regulatory Agency or Consensus Organization	OEL, 8-Hour TWA (mg/m^3 [ppm])	OEL, Ceiling (mg/m^3 [ppm])	Other Notations
OSHA	- [A]	0.2 (0.02)	-
ACGIH	0.051 (0.005)	-	-
NIOSH REL	0.05 (0.005)	0.2 (0.02)	-
Germany MAK	0.05 (0.005)	0.1 (0.01)	Skin, Sah[B]

A. The (-) notation indicates that OELs have not been established.
B. The "Skin" and "Sah" notations indicate that exposure to MDI include the potential for cutaneous absorption and of the potential for sensitization of the skin and airways, respectively.

Table 1 OELs for Monomeric MDI

OSHA ceiling limit, nine were collected during spray applications of MDI-based adhesives. The author did not specify the work activities associated with the other sample results which exceeded the OSHA ceiling limit. Booth, et al. (2009) also analyzed the results of area air sampling during coating, adhesive, sealant and elastomer processes. Of these 358 area air samples, 217 of the sample results were less than the LOQ, 88 were greater than the LOQ but less than the TLV, 17 samples were greater than the TLV and less than the OSHA ceiling limit and 36 samples were greater than the OSHA ceiling limit for MDI (Booth, et al., 2009). Again, the authors did not specify the work activities associated with the area samples other than they were collected during the coating, adhesive, sealant and elastomer processes. Booth, et al. (2009) identified the following processing conditions or activities that can influence airborne MDI concentrations:

- whether the material is heated or sprayed;
- how the diisocyanate has reacted;
- whether manufacturing processes are open or closed systems;
- the type of MDI sampling method that was utilized.

The scientific literature indicated that, most generally, the spray application of MDI-based adhesives resulted in elevated airborne MDI concentrations in the workplace. Measurable MDI concentration in the breathing zone is also erratic and is typically associated with the use and processes associated with the specific formulation of the MDI-based adhesive.

Consumer Exposures to Polyurethane-Based Adhesives

Minimal literature regarding consumer use and ensuing quantifiable airborne concentrations of isocyanates is available. Hoffmann and Schupp (2009) found that unreacted MDI in commercially available polyurethane foam does not migrate from the foam's chemical composition. Similarly, in 2007, the Danish Ministry of the Environment's Environmental Protection Agency, performed a survey and health assessment of selected respiratory sensitizers in consumer products. A variety of products, including car window adhesives, polyurethane one-component sealant and adhesive, floor adhesive, as well as numerous nonrelated items, were tested for quantifiable airborne concentrations of MDI during normal use conditions. The study reported that all samples contained nondetectable airborne concentrations of MDI, which were below their respective limits of detection, which ranged from 0.2 to 17 micrograms of MDI per cubic meter (µg/m^3) of air (Boyd & Mogensen, 2007).

Limited research has been conducted regarding consumer exposure to adhesive products containing MDI and PMDI. As discussed previously, the Danish Ministry of the Environment's study found airborne concentrations of MDI during normal use conditions of car window adhesives, polyurethane one-component sealant and adhesive, and floor adhesive that were below their respective limits of detection, which ranged from 0.2 to 17 µg/m^3 (Boyd & Mogensen, 2007). Of all the studies that GZA reviewed, only this study evaluated the representative consumer uses and ensuing quantifiable airborne concentrations of MDI/PMDI-containing adhesive products.

General Health Effects & Toxicity of Isocyanate & MDI Exposure

Inhalational Exposure

The inhalational exposure to isocyanates is highly dependent on the physical and chemical composition of the materials and the usage of the product (including heat and pressure), and it is often directly related to the vapor pressures of the individual isocyanate compounds, as well as the volume and surface area of the materials utilized. Lower molecular weight isocyanates volatilize at room temperature creating an airborne vapor. Higher molecular weight isocyanates, including MDI, do not readily volatilize at room temperature and do not become airborne. The inhalation of MDI and other higher molecular weight isocyanates results from aerosol generation during spray application or from increased temperature of MDI or PMDI.

Workplace inhalation of MDI has the potential to sensitize select workers and predispose them to asthma and other respiratory conditions (EPA, 1998). However, a definitive dose-response relationship for these health effects has not been established. The relationship of MDI and adverse health effects is confounded by multiple factors, including but not limited to, the sensitization process and immunologic and genetic responses. The immunologic and genetic responses have been identified in several studies where workers, especially those exposed to elevated MDI concentrations during spills or work practices, have subsequently developed MDI-related asthma (EPA, 1998). Occupational dermal exposure, especially during MDI-based polyurethane foam spraying activities, in the absence of PPE, has also been noted as a potential mechanism for the induction of MDI sensitization.

It is evident in the scientific literature that expandable foam and spray foam MDI-based polyurethane products have the potential for increased worker exposure to isocyanates; however, in numerous workplace studies, both area and personal breathing zone concentrations vary significantly, as well as the work practices employed by the workers. The airborne concentrations of MDI vary considerably generally due to a variety of conditions including, but not limited to, the mechanism of application, ventilation conditions and distance from foam application, as well as concentration of MDI and PMDI in the foam substrates.

Isocyanate exposure, whether in the vapor or aerosol state, is generally irritating to the skin, mucous membranes and the respiratory tract. Most frequently, isocyanate-induced occupational asthma may result from the inhalation of isocyanates, which may be followed by dermal sensitization. In fact, EPA's (1998) toxicological review of MDI reported that exposure to isocyanates is the leading cause of occupational asthma worldwide. A cross-sectional study by Bernstein, Korbee, Stauder, et al. (1993) evaluated MDI-induced respiratory sensitization in 243 PMDI/MDI foam workers in a facility with 24-hour monitoring of PMDI/MDI, during which time airborne concentrations of PMDI/MDI never exceeded 5 ppm.

Respiratory exposure to isocyanates may produce respiratory irritation within 4 to 8 hours after exposure to elevated, generally greater than the OSHA ceiling limit, airborne concentrations of isocyanates (Bilan, Haflidson & McVittie, et al., 1989). Bello, Herrick, Smith, et al. (2007) stated that 1% to 25% of the population occupationally exposed to isocyanates develops occupational asthma, whereas Krone (2004) reported cases of asthma in 3% to 13% of all workers exposed to isocyanates. Bello, et al. (2007) reported that isocyanate-induced asthma typically developed after months or years of repeated exposure of these workers who utilized isocyanate polyurethane products. Bello, et al. (2007) also found that, less frequently, occupational exposure to isocyanates can cause hypersensitivity pneumonitis, contact dermatitis and rhinitis, some of which are transient while others may be encountered episodically.

EPA's (1998) toxicological review of MDI established the inhalation reference concentration (RfC) for MDI. The RfC is an estimate, with uncertainty spanning approximately an order of magnitude, of the daily exposure to the human population including sensitive subgroups that is likely to be with appreciable risk of deleterious non-cancer effects during a lifetime. The calculated RfC for PMDI/MDI is 0.6 μg/m^3. However, it is important to note that the RfC was derived using a chronic inhalation study in rats with basal cell hyperplasia of the rat's olfactory epithelium as the effect that was used as the basis for the RfC.

This study was selected due to the absence of adequate chronic data in humans for either asthma or pulmonary function. There is a lack of scientific literature demonstrating a dose-response relationship between airborne exposure to MDI and the development of asthma or isocyanate-induced sensitization, thus confounding the establishment of a quantitative exposure related to respiratory effects in humans. EPA (1998) reported, "The available human data concerning occupational exposure to PMDI/MDI, coupled with lack of knowledge about mechanism of action and the possible role of genetic predisposition, are insufficient to identify exposure levels and scenarios responsible for isocyanate-induced sensitization."

Summary

As a result of the literature review, we have not identified any studies or other documentation that would indicate unreasonable inhalational exposure to MDI from MDI-containing pourable adhesive products, such as Gorilla Glue, used in a nonoccupational consumer setting. Based on the low vapor pressure of MDI and PMDI, and the authors' review of the applicable scientific literature that revealed that minimal airborne MDI was measured during the use of MDI-based adhesives, the authors hypothesized that minimal, if any, MDI or PMDI would be detected during the simulated consumer use of MDI- and PDMI-containing Gorilla Glue. The following methods were developed to measure airborne MDI concentrations during simulated consumer use.

Methods

The objective of this study was to measure the airborne vapor or aerosol concentrations and related potential exposure to consumer MDI- and PMDI-based adhesives. A work practice simulation study using MDI- and PMDI-based consumer adhesives, namely Gorilla Glue, while quantitatively evaluating airborne concentrations of MDI during standard and hypothetical maximal worst-case consumer use was performed. The following provides methods to evaluate ventilation in the laboratory space utilized for the study by measuring the number of room air exchanges per hour. The authors sought to minimize dilution ventilation to maximize detection of airborne MDI.

Ventilation

The laboratory space used during sample collection was not equipped with a ventilation diffuser or an intake for the building's forced air ventilation system. Rather, the laboratory space was equipped with a hot-water or steam radiator for heating purposes. The 24 m^3 laboratory space was a room in a multistory, multiroom engineering building at the University of Wisconsin-Milwaukee, with sealed windows located on the north wall and a door on the south wall.

At the start of the sampling, the outdoor temperature was 70.3 °F and laboratory's temperature was 74.8 °F with 41.8% relative humidity. The laboratory space had no local exhaust ventilation and the door to the laboratory remained closed during the duration of the sampling procedures. Sulfur hexafluoride (SF_6) (Sigma Aldrich, St. Louis, MO), an inert, nontoxic gas, was used as a tracer to estimate the rate of air exchange within the laboratory space. Air measurements of the SF_6 were collected following ASTM International Method E741-111, Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution, using a Foxboro 100XL SapphIRe® (Thermo Electron) infrared spectrophotometer. A box fan was utilized to facilitate even dispersion of the tracer gas. Air measurements of SF_6 were collected at 1-minute intervals over a period of 2 hours, beginning after a steady

state SF_6 airborne concentration of 72 ppm was measured. The airborne concentration decay method, as listed below, was utilized, with the assumption of constant air change, as follows:

$$\ln Ct = -At + \ln C0$$

where t corresponds to time in hours (after steady state SF_6 airborne concentration is achieved), Ct represents concentration at time t, and C0 was the initial airborne concentration.

A regression of lnCt at t was performed where the slope of the regression line equals the air exchange rate. The air exchange rate in the laboratory was calculated at 1.15 hr-1, which is consistent with forced air ventilation not being present in the laboratory.

Study Protocol

The study was conducted in June 2012, at the University of Wisconsin-Milwaukee in cooperation with the Zilber School of Public Health, in a 24 m^3, or approximately 10-ft x 10-ft x 8-ft laboratory space, located in the Engineering and Applied Sciences Building (2200 E. Kenwood Ave., Milwaukee, WI). Six 2-fluid ounce bottles of Gorilla Glue from the same lot number, with the most recent manufacturing date, as indicated by the lot number, were purchased from a local hardware store. (The lot numbers and manufacturing dates are included in Table 2.)

Prior to the initiation of the study, the laboratory space was visually evaluated for the presence of proximal isocyanate-containing materials with none being identified. Also, prior to the initiation of the work with the Gorilla Glue, the laboratory work surfaces were thoroughly wetted with DECON® isocyanate decontamination solution (Colorimetric Laboratories Inc.) which was allowed to react for 5 minutes followed by rinsing of the laboratory bench with water. New nitrile gloves were donned by the study scientists prior to each sampling session. An MSA Escort® brand personal sampling pump was calibrated to a flow rate of 2 liters per minute (LPM) utilizing a BIOS Defender® 510M dry primary calibrator before and after sampling. The sampling train was connected to IsoChek® sampling media (Omega Specialty Instrument Co.) for collection of airborne monomeric MDI and PMDI. IsoChek® laboratory analysis for monomeric MDI and PMDI established a lower limit of detection of 0.0005 mg/m^3.

The air sampling was performed in the personal breathing zone (PBZ) of the study subject. The air sampling pump was activated while a 1 gram sample of Gorilla Glue was weighed using a calibrated and tared laboratory balance and placed onto a water-moistened, 4-in. x 2-in. x 1/8-in. thick pine furring strip (furring strip). One gram of Gorilla Glue was approximately the diameter of a U.S. quarter coin. After the Gorilla Glue was applied to the furring strip, the glue remained undisturbed for precisely 1 minute before clamping this furring strip to a second moistened furring strip. Air sampling for MDI in the PBZ continued for 30 minutes during this work practice. As noted, the PBZ air sampling was then repeated utilizing a 2-gram sample of Gorilla Glue and utilizing identical sampling and work practice parameters, which remained undisturbed for exactly 5 minutes prior to clamping of the two furring strips. Two grams of Gorilla Glue were approximately the diameter of a U.S. half-dollar coin. The PBZ air sampling was then repeated, as previously described, while applying a 30-gram sample of Gorilla Glue onto a 1-ft square section of plywood, allowing the applied Gorilla Glue to remain undisturbed for 5 minutes before the clamping process began. Thirty grams of Gorilla Glue covered approximately one-half to two-thirds the surface area of the 1-ft by 1-ft piece of plywood. It should be noted that this quantity of glue is approximately double the rate of glue application recommended by the manufacturer, which likely results in excessive glue squeeze out between the plywood. Two background samples were initially collected in the PBZ before opening any of the Gorilla Glue 2-ounce bottles. One IsoChek® sampling cassette was utilized as a field blank. The air samples were shipped via chain-of-custody protocol to Galson Laboratories (East Syracuse, NY), an American Industrial Hygiene Association-accredited laboratory for modified IsoChek® analysis of monomeric MDI and PMDI.

Results

The analytical sample results for airborne monomer and oligomer MDI concentrations were less than the analytical limit of detection (< 0.0005 mg/m^3). Increasing the time when the entire surface area of the glue was exposed to the ambient conditions prior to clamping the wood, as well as increasing the mass of glue (from 1 to 30 grams) utilized, or the surface area (from furring strip to plywood) to which the glue was applied, had no measurable impact on the airborne MDI concentration. Table 2 (p. 150) provides the results of the airborne sampling.

Discussion

MDI is one of several isocyanates used in a variety of consumer products. Recently, MDI has become the most commonly used isocyanate. The low vapor pressure of MDI reduces the potential for vapors or aerosols to become airborne. MDI is most often used in spray and expandable polyurethane foam, but is also used in selected liquid adhesives, like Gorilla Glue. Gorilla Glue adhesives contain to contain a mixture of monomeric MDI and PMDI, and are designed as waterproof adhesives for consumer use. In contrast, polyurethane foam products, which are created when the foam is sprayed or poured, are used in many consumer products including mattresses, home thermal insulation, Spandex™, automobile furnishings, furniture, footwear, boats, surfboards, packaging, golf balls and carpet underlay. MDI and PMDI are also poured or cast to form polyurethane adhesives.

When the foam materials that contain MDI are sprayed, airborne vapors or aerosols can be released due to the manner in which it is processed, the volume of materials utilized, surface area of the materials, temperatures of the process and other factors. Several studies have been conducted that measured airborne MDI concentrations during the spraying of polyurethanes that contained MDI. In general, several of these studies found airborne concentrations that exceeded the OSHA MDI ceiling limit when associated with large-volume commercial or industrial spray applications of MDI-containing products

Sample ID	Air Volume (L)	Gorilla Glue (g)[A]	Wait Time Before Clamping (min)[B]	Wood Type	Monomer and Oligomer Concentration (mg/m^3)[C]
1-Control	60	0	n/a	Furring	<0.0005
2-Control	60	0	n/a	Furring	<0.0005
3	60	1.02	1	Furring	<0.0005
4	60	1.01	1	Furring	<0.0005
5	60	1.99	5	Furring	<0.0005
6	60	1.99	5	Furring	<0.0005
7	60	30.45	5	Plywood	<0.0005
8	60	30.83	5	Plywood	<0.0005
9-Field Blank	n/a	n/a	n/a	n/a	<0.0005

A. Mass of glue applied.
B. Time in minutes from application of the glue to clamping of the adjoining wood.
C. mg/m^3 = milligrams of MDI per cubic meter of air.
Note: Gorilla Glue lot number 12 122 was utilized in this study, indicating that the glue was manufactured on May 1, 2012.

Table 2 MDI monomer and oligomer airborne sampling results

where hundreds or thousands of gallons of MDI-containing products were used. Comparatively, only a few grams of Gorilla Glue are typically used during standard consumer use of this one-component adhesive and this adhesive is manually applied and not sprayed in any means.

A limited number of studies have been conducted to evaluate dermal exposures to MDI when polyurethane foams were sprayed. These studies are inconclusive, but suggest that MDI may be related to dermal sensitization when used in spray foam applications. The potential toxicity of MDI and PMDI has been evaluated for workers who experienced chronic exposures. The toxicological effects apparent in these workers have included respiratory conditions, including occupational asthma and undefined sensitization, as well as select dermal effects. The authors were unable to identify any scientific literature supporting a causative relationship between pourable, one-component MDI adhesives, like Gorilla Glue, and the development of asthma or any other physical anomaly.

Very limited studies are available that have evaluated the use of MDI-containing adhesive products. One study evaluated the emission rates of MDI from adhesive systems while another study that used a pourable adhesive product, similar to Gorilla Glue, found nondetectable concentrations of airborne MDI when adhesives were utilized. However, large volumes of this adhesive that contained MDI were utilized in the process that resulted in a significantly large surface area of the MDI adhesive being present, as opposed to the smaller volume and surface areas that are used with Gorilla Glue.

Few studies have been conducted to evaluate the consumer use of adhesive products containing MDI. In two studies, airborne MDI vapor or aerosol were not detected. It should be noted that these studies were conducted on processes that utilized far greater volumes of MDI with a much larger surface area of the MDI being applied as compared to the consumer use of Gorilla Glue.

During the collection of air measurements in this study, demonstrated by the air exchange rate in this study, the ventilation in the laboratory was minimal due to the absence of heating or air conditioning ventilation ducts, or an air intake. This is important because consumer use of Gorilla Glue may occur in spaces with limited ventilation such as closets, basements or garages. Laboratory analysis of air samples collected during this study for monomeric MDI and PMDI (oligomeric) revealed airborne concentration of less than the limit of analytical detection of 0.0005 mg/m^3 for MDI. Increasing the mass of glue, the time when the entire surface area of the glue was exposed to ambient conditions prior to clamping, and the surface area to which the glue was applied (furring strips and plywood), did not impact airborne MDI concentrations. These analytical results were not surprising, as MDI has a very low vapor pressure and is commercially utilized in numerous products based on its lack of volatility. Given that Gorilla Glue is used as a consumer product for numerous applications, the sampling and analysis conducted in this study provided confirmation that airborne concentrations of isocyanates that occurred during typical consumer use of Gorilla Glue was nondetectable. It can be concluded that airborne concentrations will not likely exceed applicable OELs during the use of Gorilla Glue under the conditions presented in this study.

While this study was focused on inhalational exposures, the authors considered the potential for dermal exposure to Gorilla Glue during this exposure study. Recent research revealed occupational spray exposure to HDI, an aliphatic isocyanate, is measurable using a dermal patch system (Thomasen & Nylander-French, 2012). However, despite advances in the ability to measure skin exposure to isocyanates, little is known about human dermal absorption of MDI or other isocyanates (Thomasen & Nylander-French, 2012). Recent research in mice demonstrated that MDI-induced immune sensitivity and promoted subsequent respiratory track inflammatory responses (Wisnewski, Xu, Liu, et al., 2011). However, the researchers used varying doses of 0.1% to 10% w/v MDI dissolved in an acetone/olive oil delivery to provide for the mixture's penetration of the dermal barrier of the mice (Wisnewski, et al., 2011).

Generally, the consumer use of the Gorilla Glue product consists of a small volume application of the glue to a variety of materials, followed by clamping or otherwise securing the materials and allowing the glue to dry or cure. Minimal skin contact is expected. The authors theorize that when a minimal volume of Gorilla Glue inadvertently contacts the skin, consumers would likely remove the sticky adhesive from hands and surfaces during clean up, thus minimizing the duration of exposure and absorption, if any.

No information is available in the published scientific literature regarding MDI-containing consumer adhesive products, similar to Gorilla Glue, penetrating the skin or inducing an inflammatory response in humans or animals. The literature reviewed in this paper found that a complex immunologic response, which, in some workers, leads to isocyanate sensitivity and subsequent asthma or other health sequelae may result. The literature demonstrated that occupationally exposed workers who have a consistent, extensive and prolonged duration of isocyanate exposure, whether that exposure is related to the dermal, inhalation or both routes of entry are most frequently sensitized. Gorilla Glue is composed of both MDI and PMDI, and this study demonstrated that the airborne concentration of either form of MDI during the consumer use was nondetectable. Future research may be warranted to determine the extent of dermal exposure, if any, during consumer use of Gorilla Glue and other isocyanate-containing consumer adhesives. ✪

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