Predictors of Safe Work Behavior and Central Nervous System Toxicity Symptoms in the Dry-Cleaner Workforce

by

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DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Nursing

[redacted]

Dedication

This dissertation is dedicated to my daughter, Soraya, who has been a constant source of joy. As a toddler, she has taught me the meaning of the word “persistence”, which is just what I needed to get through this program. To my husband, Jacob, who has encouraged and supported me throughout this process. To my mom, Dr. Aniss Bahreinian, who has inspired my passion for learning and teaching.

Acknowledgements

I would like to thank Dr. Oisaeng Hong, my doctoral advisor. Her continued support and patience allowed me to grow as a researcher and life-long student. I would also like to thank the other members of my dissertation committee: Dr. Lisa Thompson, her enthusiasm and guidance made me excited about research. Dr. Soo-Jeong Lee, I learned so much from her thoughtful and meticulous feedback and her honest opinion. Finally, I would like to thank Dr. Abbey Alkon, I would have not graduated from this program if it were not for her. I am thankful that she saw promise and potential in me when I could not.

I would also like to acknowledge Dr. Bruce Cooper and Dr. Dal Chin for their assistance with data analysis. Patricia Quinlan for taking the time to share occupational health resources and to provide an industrial hygienist perspective. Dr. Barbara Burgel for being my occupational health nurse mentor. Dr. Robyn Gershon for providing much needed guidance during my qualifying exams. Ms. Sharon Solorio for organizing learning opportunities and providing guidance. Dr. Avima Ruder for being my expert reviewer.

I wish to acknowledge my classmates who were there to commiserate with me as well as to motivate me to continue my work. I especially would like to thank Dr. Julia Buss for her friendship, support and guidance throughout this process. I am thankful to have had the opportunity to learn, grow and share many great memories with you. I also wish to thank Dr. John Merriman for being a dear friend and an excellent editor, I am inspired by your genius.

Finally, I would like to acknowledge all of my friends and extended family for their never- ending support. I am so fortunate to have such a loving and inspiring group of individuals in my life.

This dissertation was supported by: National Institute for Occupational Safety Health (NIOSH) Targeted Research Traineeship Grant: A117464. Funding for the original study was provided by NIOSH Grant: Grant number: T42 OH008455-01 (PI: Hong). I am also thankful to have had my education funded by NIOSH T42 grant and Kaiser Permanente.

Chapter 3 of my dissertation, “Self-Reported Central Nervous Toxicity Symptoms in the Dry-Cleaner Workforce: A Cross-Sectional Study”, was submitted and is under review by the International Journal of Occupational and Environmental Health.

Predictors of Safe Work Behavior and Central Nervous System Toxicity Symptoms in the Dry-Cleaner Workforce

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Abstract

Background: Occupational exposure to solvents, such as perchloroethylene has been associated with neurotoxicity. Within the dry-cleaner population, several technological advances have reduced exposure to solvents, however little research has been conducted to ensure that workers are adequately protected. Therefore it is important to determine the prevalence of central nervous system (CNS) toxicity symptoms in a recent dry-cleaner worker population. It is also necessary for workers to engage in safe work behaviors to further reduce exposure to solvents. Hence, an understanding of predictors that promote engagement in safe work behavior is important.

Objective: The aims of this research were: 1) summarize existing research on CNS toxicity symptoms that are associated with perchloroethylene exposure below 100 parts per million. 2) assess the prevalence of CNS toxicity symptoms in dry-cleaners exposed to organic solvents. 3) identify predictors of safe work behavior among dry-cleaners.

Methods: Articles for the literature review were primarily selected from three search engines of peer-reviewed literature. Secondary analysis of an existing cross-sectional dataset of a convenience sample of198 dry-cleaner workers, working primarily in the Midwestern United States. Data collection included self- reported information regarding personal and work-place characteristics, personal beliefs regarding health effects and sources of solvent exposure, symptoms experienced within the prior twelve month period use of personal protective equipment (PPE) and engagement in personal protective behavior (PPB).

Results: In total 14 of the 15 articles reviewed found perchloroethylene exposure below 100 ppm was associated with at least one symptom of CNS toxicity. Symptoms associated with perchloroethylene exposure included: visual impairment, dizziness, motor-coordination deficits, impaired memory and attention deficits. The secondary data analysis revealed that, controlling for use of PPE, workers in the high exposure group were four times more likely (prevalence risk [PR]=4.2; 95%CI 0.9-19.6) to report memory loss and three times more likely (PR= 3.4; 95%CI 1.1-10.7) to report loss of visual perception compared to their counterparts in the low/ moderate-exposure group, however, being an owner was the strongest predictor for CNS toxicity symptoms. In regards to engaging in safe work behavior, receiving safety training and working in high exposure group predicted PPB with the final model explaining 30% ($p<.001$) of variance. Being an owner, male, having a lower perceived exposure score, and using an alternative solvent to perchloroethylene predicted PPE use, explaining 32% ($p<.001$) of variance.

Conclusion: Both the literature review and the descriptive study highlight the need for more rigorous research to better understand the risk of CNS toxicity and predictors of safe work behavior in the current dry-cleaner workforce exposed to solvents. Future interventions to increase engagement in safe work behavior should focus on increasing personal protective equipment use among dry-cleaners, especially those who use Perchloroethylene.

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Table of Abbreviations

Abbreviation	Definition
ACGIH	American Council of Governmental Industrial Hygienist
ARB	Air Resources Board
CCI	Color Confusion Index
CNS	Central Nervous System
CPD	Cycles Per Degree
CPT	Continuous Performance Test
EPA	Environmental Protection Agency
IARC	International Agency for Research on Cancer
ICIS	Independent Chemical Information Services
NIOSH	National Institute for Occupational Safety and Health
OHP	Occupational Health Practitioner
OSHA	Occupational Safety and Health Administration
PCE	Perchloroethylene
PE	Perceived Exposure (Sources)
PEL	Permissible Exposure Limit
PPB	Personal Protective Behavior
PPE	Personal Protective Equipment
PPM	Parts Per Million
PS	Perceived Susceptibility
SWB	Safe Work Behavior
TWA	Time Weighted Average
VCS	Visual Contrast Sensitivity
VEP	Visual Evoked Potential
WHO	World Health Organization

Chapter 1

Introduction

Chapter 1

Introduction

Injury and Illness Rates in the Dry-Cleaning Sector

In 2013 the illness and injury rate requiring time away from work due to "exposure to harmful substances or environments" was 4.4 per 10,000 full-time workers in the private sector versus 13.7 in the dry-cleaning and laundry sector (United States Bureau of Labor Statistics, 2015). This number is likely a substantial underestimation of the burden of illnesses and injuries within the industry because this only accounts for days missed from work, illnesses may be subtle or latent (Committee of Education and Labor, 2008; Wiatrowski, 2014) and because injuries may be substantially under-reported in small industries (Morse et al., 2004). One source of both illness and injury in the dry-cleaning workforce is occupational exposure to organic solvents. Organic solvents are substances that can dissolve other substances. They are found in a cleaning products, polishes, glues, paints and degreasing agents, (National Institute for Occupational Safety and Health [NIOSH], 2013).

Central Nervous System Toxicity Symptoms

Exposure to organic solvents can cause central nervous system (CNS) toxicity symptoms (Agency for Toxic Substances and Disease Registry [ATSDR], 2007). The CNS is comprised of the brain and spinal cord, which function to control the entire nervous system and serve as a central conduit for sensory and motor impulses (Dougdale, 2014). For the purposes of the proposed research, CNS toxicity is defined as altered neurological activity within the CNS. This can result in impaired thinking, memory loss, impaired perception, vision loss, dizziness, fatigue, slowed reflexes, and tinnitus (Berde & Strichartz, 2000). CNS toxicity symptoms such as dizziness, vision loss and impaired thinking can contribute to increased risk of falls and other workplace injuries in addition to being indicators of CNS toxicity.

Pathophysiology and Chemical Properties of Perchloroethylene

Workers in the dry-cleaning industry are primarily exposed to one solvent, Perchloroethylene (PCE) (CINET Professional Textile Care, 2011). Routes of exposure include inhalation, ingestion and dermal contact. Approximately 75% of inhaled PCE is absorbed by the lungs and 80% of ingested PCE is absorbed by the gut (ATSDR, 2007). PCE is lipophilic meaning that it can accumulate in the fatty tissue, thus making the CNS very susceptible to its effects. The estimated half-life of PCE in adipose tissue is 55 hours and 12-16 hours in highly vascularized tissues (ATSDR, 2007). This, combined, with the relatively slow excretion of PCE suggests that even chronic, low-level exposure of PCE over a long period of time may have potentially deleterious effects on the CNS.

Prevalence of PCE Use

It is expected that demand for PCE will grow by 1.5% per year, although demand is expected to eventually decrease due to pending bans of PCE in some dry-cleaner settings (Marisol, 2011). Substantial evidence of the carcinogenicity of PCE prompted the International Agency for Research on Cancer (IARC) to classify PCE as a probable human carcinogen (IARC, 1997). As a result, there is a growing consciousness of, and pending restrictions on PCE use. Even so, 70% of the 36,000 dry-cleaning facilities in the U.S. continue to use PCE (CINET Professional Textile Care, 2011).

Several other occupations use PCE as well, including, but not limited to, degreasing operations (ranging from metal fabrication operations to railroad maintenance workers), paper production, production of electronic components and in chemical manufacturing (Gold, De Roos, Waters, & Stewart, 2008). It is also used as a chemical intermediary in the production of chlorinated fluorocarbons (Marisol, 2011).

PCE Laws

The current Federal Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) is 100 parts per million (ppm) time weighted average (TWA) over a typical eight-hour workday (OSHA, 2012). Several studies have found an association between PCE exposure and CNS toxicity symptoms at levels below the current PEL (Altmann, Neuhann, Kramer, Witten, & Jermann, 1995; Altmann, Wiegand, Bottger, Elstermeier, & Winneke, 1992; Cai et al., 1991; Cavalleri et al., 1994; Echeverria, White, & Sampaio, 1995; Ferroni et al., 1992; Gobba et al., 1998; Stewart, Baretta, Dodd, & Torkelson, 1970; Storm et al., 2011). Given the substantial body of evidence, in 1988 OSHA tried to reduce the PEL to 25ppm but was unsuccessful in doing so (American Federation of Labor and Congress of Indus. Organizations v. Occupational Safety and Health Admin, 1992).

The Environmental Protection Agency (EPA) has had more success in regulating and reducing PCE levels. In order to protect the public's health, the current reference air concentration is 0.006 ppm (EPA, 2014b) and water concentration levels must not exceed five parts per billion in the general water supply (EPA, 2014a). In addition, the requirement to replace existing transfer machines with closed-loop machines has also helped to reduce outdoor air concentration levels (EPA, 2008). While these levels have decreased the general public's exposure to PCE, workers may still be at risk of exposure to PCE levels that are potentially harmful to their health under current OSHA laws.

Controlling Exposures

In order to best control occupational exposure to hazardous chemicals such as PCE, National Institute for Occupational Safety and Health (NIOSH) recommends a hierarchy of controls focusing on: elimination, substitution, engineering controls, administrative controls, and personal protective equipment. (NIOSH, 2010). Within the dry-cleaning industry, substitution such as switching solvents can be cost prohibitive (Hesari, Francis, & Halden, 2014). However the use of engineering controls (dry-to-dry machines) is now common practice after the 1993 EPA ruling requiring dry-cleaner facilities to purchase closed-loop machines to replace transfer machines (EPA, 1993). Even with the implementation of these engineering controls, workers may still be at risk of exposure to high levels of solvent during cleaning and maintenance of machinery (NIOSH, 1997) as engineering controls are not as protective during those times. Therefore it is beneficial to ensure safe work behavior (SWB) including the use of personal protective equipment (PPE) and engaging in personal protective behavior (PPB) such as not overloading or opening the machine door mid-cycle.

Insufficient use of correct PPE and lack of engagement in recommended PPB has been described in the current literature (Goldenhar et al., 1999; Whittaker & Johanson, 2013). In their qualitative study, Goldenhar et al. (1999) noted that owners were not concerned about PCE exposure, frequently did not use PPE and believed that use of dry-to-dry machines alone provided adequate protection. Some of the workers interviewed were more concerned about PCE exposure, however they could not describe any health effects associated with exposure (Goldenhar, et al., 1999). A better understanding of factors that promote SWB is needed in order to develop interventions that can further decrease worker exposure to harmful chemicals.

Other Factors Impacting Exposure

The 210,000 workers in the dry-cleaning and launderer industry (Bureau of Labor Statistics, 2014) work in an inherently risky work environment, which is further compounded by lack of regulation and limited educational attainment. The dry-cleaning sector consists of mainly small worksites that employ less than 10 employees (NIOSH, 2012), with little oversight provided by federal regulating agencies such as OSHA. Only worksites with more than ten workers are required to have an injury and illness prevention program (California OSHA, Title 8, CCR Section 3203) thus limiting any formal or standardized workplace safety program (California OSHA, 1991).

Several factors may hinder a worker's ability to fully understand SWB and employer responsibility for creating a safe work environment. Pechter et al. (2005) noted that language barriers and lack of training and minimal supervisor support contributed to health outcomes associated with chemical exposure in janitors (Pechter et al., 2005). In regards to education, 98% of workers in this industry have a high school diploma or less (National Center for O*NET Development, 2010). A cross-sectional study of 475 dry-cleaners in Washington revealed that 84% of workers prefer to receive information in a language other than English (Whittaker & Johanson, 2013).

Although CNS toxicity symptoms associated with solvent (primarily PCE) exposure has been well established, the last study of CNS symptoms in dry-cleaners occurred in 1995 (Echeverria, et al., 1995). Since then the use of dry-to-dry machines has become more common and therefore exposure is presumed to have decreased. More research is needed in order to determine if workers are being adequately protected with the use of new technologies and new solvents.

Given that workers are still being exposed to solvents, it is important to determine factors that promote and discourage engagement in SWB in order to further reduce solvent exposure.

Purpose and Aims

The purpose of this dissertation study is to determine what factors promote and hinder dry-cleaner shop workers from engaging in SWB that protect against solvent exposure. Furthermore this study will describe self-reported CNS toxicity symptoms associated with organic solvent exposure. In order to inform current research and policy, a literature review focusing on research gaps and policy implications was also conducted. The specific aims for this dissertation include:

Aim 1: To summarize existing research on CNS toxicity symptoms that are associated with PCE exposure below 100ppm.

Aim 2. To describe the prevalence of CNS toxicity symptoms in dry-cleaners exposed to organic solvents.

Aim 3: To identify predictors of SWB.

Significance

A description of workplace and personal characteristics among dry-cleaning facility employees will provide an overview of some key characteristics that increase risk for CNS toxicity symptoms. Identifying factors that increase risk for CNS toxicity allows occupational health professionals to determine which workers are most at risk for CNS toxicity as well as helps to substantiate the need for further research and new interventions. Because the last study of CNS toxicity symptoms was published in 1995, this research establishes the prevalence of self-reported CNS toxicity symptoms in a more recent dry-cleaner workforce, who may be exposed to lower PCE levels and alternative solvents.

Because dry-cleaner facility employees are exposed to solvents and even low-level solvent exposure has been associated with deleterious health outcomes, employee engagement in SWB to decrease solvent exposure is essential. This research identifies both personal and workplace characteristics that promote or hinder engagement in SWB as well as determines the prevalence of SWB. Understanding these predictors can inform current dry-cleaner facility site inspections and help develop more targeted occupational health and safety training.

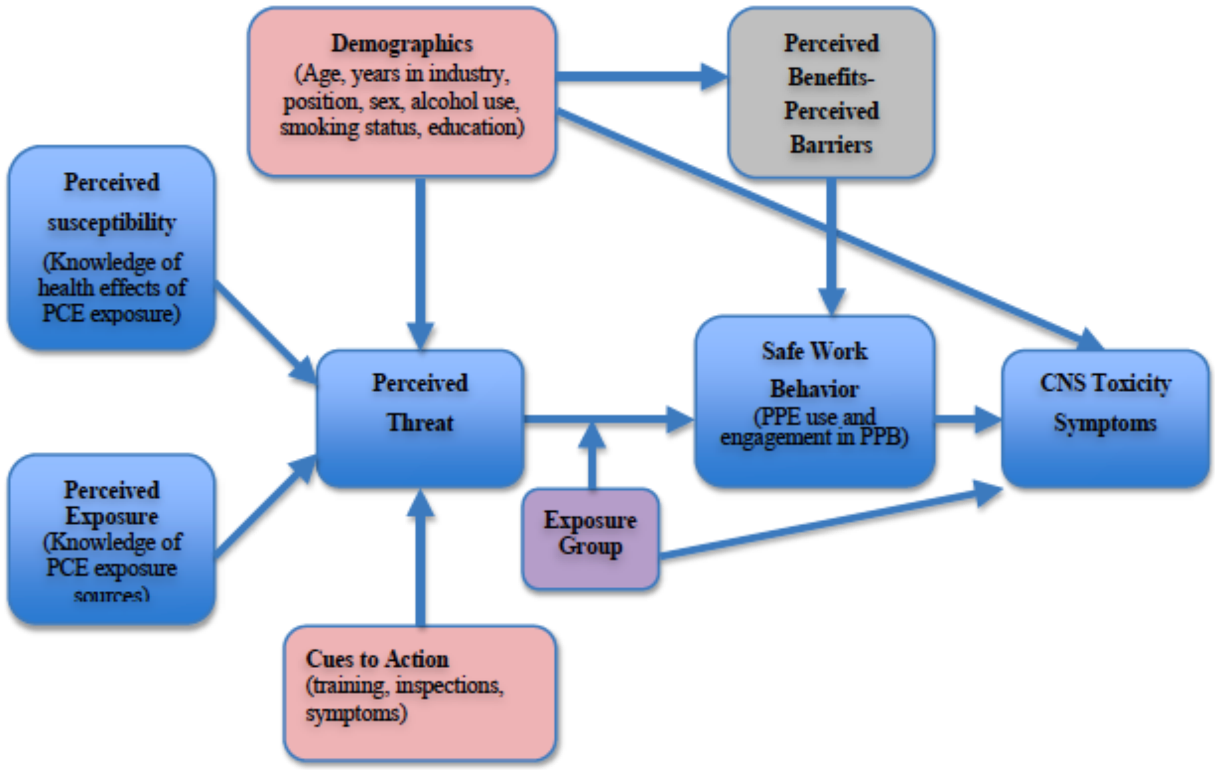
Conceptual Framework

In order to address the aims of this research a conceptual model was developed, as shown in *Figure 1*. This conceptual model is based on Rosenstock and Hochbaum's (1966) Health Belief Model (HBM) (Rosenstock, 1966). The underlying assumption of the HBM is that a person will engage in safe behavior if he/she regards himself/herself as susceptible to a given threat (perceived susceptibility), that the consequences are severe (perceived severity), that the benefits (perceived benefits) outweigh the risk (perceived barriers) and that engaging in the behavior will actually decrease the risk. The HBM posits that a stimulus or trigger is needed in order to prompt engagement in preventive behavior, this is referred to as a *cue to action* (Glanz, Rimer, & Lewis, 2002). In addition to the HBM, the construct *perceived exposure* was added to the conceptual model in order to better explain SWB. As will be discussed in more detail, the construct, *perceived exposure* replaced '*perceived severity'*. The combination of *perceived exposure* and *perceived susceptibility* is referred to as *perceived threat*.

The HBM focuses on behaviors and beliefs at the individual level, thus it is an appropriate model to examine SWB. At the individual level, workers can decrease their exposure to PCE through engaging in SWB consisting of PPE use and engaging in PPB that decrease exposure to organic solvents.

Figure 1

Proposed Conceptual Model Explaining Predictors of Safe Work Behavior Central Nervous System Toxicity Symptoms in Dry-Cleaners.



Outcome Constructs

CNS toxicity symptoms is the outcome variable of interest for Aim 2. While PCE exposure causes several symptoms, CNS toxicity symptoms only refers to symptoms identified by Berde and Strichartz (2000) to be indicative of CNS toxicity. These include the loss of visual perception, memory loss, dizziness and tinnitus. Hypothesized predictors include: exposure group, SWB and demographic variables.

Safe work behaviors refer to the work practices that employees engage in to protect themselves from chemical exposure, it is the outcome variable for Aims 3. These include use of PPE that minimized PCE exposure and following the personal protective behavior (PPB) practices recommended by OSHA to reduce PCE exposure. Per the model, perceived threat directly predicts SWB; however, cues to action and demographic variables can impact SWB. *Exposure symptoms* are predicted by the demographic and SWB constructs. Exposure symptoms can also serve as a cue to action and thus influence SWB.

Predictor Constructs

Perceived susceptibility refers to an individual's assessment of his or her probability of developing a given health problem (Glanz, et al., 2002). The underlying assumption is that the more susceptible a person views herself as being, the more likely that she will engage in protective behavior. Within the proposed study, perceived susceptibility is defined as a worker's perception of risk of experiencing a symptom or disease associated with chemical exposure. Several studies have found knowledge and perceived susceptibility to be a moderate but significant predictor of SWB in workers exposed to toxic chemicals (Ben-Ami, Shaham, Rabin, Melzer, & Ribak, 2001; Martinez, Gratton, Coggin, Rene, & Waller, 2004), while Arcury et al. (2002) found risk perception of symptoms to be a weak predictor of some protective behaviors in farm workers exposed to pesticides. Martinez et al. (2004) noted that while many workers had an understanding of exposure sources, knowledge of health effects of pesticide exposure were low and thus may have influenced the lack of association between knowledge and risk perception.

P*erceived (sources of) exposure* refers to the assessment that various work activities are a source of solvent exposure. Perceived exposure is included in this model based on a preliminary analysis of the data and a review of the literature indicating that many workers believed that they were not being exposed to PCE (Goldenhar et al., 1999). Because perceived severity is the weakest predictor of behavior (Janz & Becker, 1984), perceived exposure replaces perceived severity in the proposed conceptual model.

The combination of perceived susceptibility and perceived sources of exposure is referred to as *perceived threat*. Perceived threat directly influences SWB. For the proposed study, perceived threat refers to an individual's assessment of her beliefs that she is being exposed to PCE and that PCE has deleterious health effects.

Perceived barriers refer to obstacles that impede engagement of a particular behavior (Glanz, et al., 2002). This definition slightly differs from the definition of perceived barriers to work behavior in the proposed model, which refers to the negative aspects in engaging in SWB, examples of these include: inconvenience, cost and discomfort. Also, the proposed research measures barriers only in workers who are not engaging in SWB. In their meta-analysis of HBM studies Janz & Becker (1984) found perceived barriers to be the strongest predictor of health promotion behavior.

Moderating constructs

According to the HBM, moderating variables indirectly affect engagement in a given behavior by amplifying or diminishing perception of threat (Glanz, et al., 2002). Perceived threat and SWB can be modified by *demographics* characteristics and *cues to action.* Demographic characteristics are characteristics that are unique to and describe the worker and their work environment. In addition to controlling for all demographic variables, the proposed model also hypothesizes that exposure group moderates relationships between perceived threat and SWB. In other words, the perception of threat associated with solvent exposure differs by workers in the high versus low exposure group.

A cue to action can either be an external influence such as training or advice from peers or internal influences such as development of symptoms (Glanz et al., 2002). If an individual already believes that he/she is susceptible and that engaging in a protective behavior will decrease risk, then a simple announcement is all that is needed for her to engage in the given behavior. Likewise, if he/she does not feel he/she is at risk then a more rigorous cue to action will be needed. Within the proposed research, internal cue to action refers presence of a symptom associated with PCE exposure while external cue to action refers to receiving training in SWB or a site inspection.

Overview of Dissertation

This dissertation is organized into five chapters. The first chapter presents background and significance of the problem, aims, and the theoretical framework that guides the research. The second chapter is a literature review of CNS toxicity associated exposure to PCE below 100 ppm. The third chapter is a descriptive study of CNS toxicity symptoms that are associated with solvent exposure. The fourth chapter uses the HBM to determine predictors of SWB behavior in dry-cleaner shop employees. The fifth chapter presents a summary of the research findings, conclusions, and implications and suggestions for future research, practice, and policy in the field of occupational and environmental health. Three publishable manuscripts are generated from Chap 2, 3, and 4.

Paper 1: Perchloroethylene Exposure and Health Effects on the Central Nervous System: A Review of the Literature

Paper 2: Self-reported Central Nervous System (CNS) Toxicity Symptoms in the Dry-cleaner Workforce: A Cross-sectional Study

Paper 3: Predictors and Barriers of Safe Work Behavior Among Dry-Cleaner Facility Employees

Chapter 2

Perchloroethylene Exposure and Health Effects on the Central Nervous System:

A Review of the Literature

Chapter 2

Perchloroethylene Exposure and Health Effects on the Central Nervous System: A Review of the Literature

Abstract

Objective: The purpose of this paper is to understand effects of PCE exposure at levels below 100 ppm on the central nervous system (CNS) through the review of current literature.

Methods: Search criteria included: studies written in English that examined the human health effects of PCE exposure at air concentration levels below 100 ppm were included in this review. Three search engines were used to identify peer-reviewed studies. In total, 15 studies met search criteria.

Results: Fourteen of the 15 studies reviewed found an association between PCE exposure at levels below 100 ppm and at least one symptoms of CNS toxicity. Four studies found an association between PCE exposure at levels below 10 ppm and at least one CNS toxicity symptom. Six studies on visual impairment, four studies on memory impairment, four studies on attention deficits, and all three studies on dizziness found significant associations with PCE exposure. Two studies also indicated that changes in vision may persist even after PCE exposure was reduced or eliminated.

Conclusion: The literature indicates that CNS functions can be impaired by exposures to PCE below 100 ppm, some of which may be permanent. The implications of the review's findings may be applied by occupational health practitioners (OHP) not only in clinical practice, but also as advocates for policy changes that better protect workers.

Introduction

Perchloroethylene (PCE) is the most common organic solvent used in the dry-cleaning industry (CINET Professional Textile Care, 2011). It is also used in metal degreasing operations, auto-mechanic shops and refrigerant industries (Marisol, 2011), as well as in some household items such as adhesives and polishes (United States Department of Health and Human Services, 2014). According to the Independent Chemical Information Services, demand for PCE in the United States was estimated to grow by 1.5% per year. However, PCE demand may eventually decrease when pending bans due to the toxicity become effective for the dry-cleaning industry (Marisol, 2011). According to the Environmental Protection Agency (EPA), PCE exposure causes irritation in the respiratory tract and eyes, kidney dysfunction, and neurological effects and also has been associated with increased risk of bladder cancer, non- Hodgkin lymphoma and multiple myeloma (EPA, 2012a). With accumulating evidence on the carcinogenicity of PCE, the International Agency for Research on Cancer (IARC) classified PCE as a probable carcinogen in 1997 (IARC, 1997). Several regulatory measures were also introduced to ban the use of PCE. The United States EPA bans the use of PCE in dry-cleaning establishments that are located in residential buildings after the year 2020 and currently mandates the replacement of dry-cleaning machines requiring manual transfer of solvents with new dry-to-dry machines to reduce air emission of PCE (EPA, 2012a). The California Air Resources Board also requires a phase-out of PCE use in dry-cleaning facilities by 2023 (Air Resources Board, 2013). Even so, an estimated 70% of dry-cleaning facilities in the United States continue to use PCE (CINET Professional Textile Care, 2011).

Routes of PCE exposure include inhalation, ingestion and dermal contact. The estimated half-life of PCE in the air is 51- 96 days (Currie, Chiao, & McKone, 1994; EPA, 1994, n.d.). An estimated 75% of inhaled PCE is absorbed by the lungs and 80% of ingested PCE is absorbed by the gut (Agency for Toxic Substances and Disease Registry [ATSDR], 2007). Within the body, the estimated half-life of PCE is 55 hours in adipose tissue and 12-16 hours in highly vascularized tissue (ATSDR, 2007). The relatively slow excretion of PCE from the body suggests that even low-level exposure of PCE over a long period may cause harmful effects.

The central nervous system (CNS) is the most susceptible body system affected by PCE. The CNS is comprised of the brain and spinal cord, which function to control the nervous system and serve as a central conduit for sensory and motor impulses (Dougdale, 2014). The effect of high-dose PCE exposure on the CNS is well known. In fact, one of the original uses of PCE was as an anesthetic (Foot, Bishop & Aspgar, 1943). In 1985, the World Health Organization (WHO) classified organic solvent-induced neurotoxicity, including PCE neurotoxicity, into three categories: 1) organic affective syndrome, in which the exposed complain of fatigue, memory impairment, irritability, difficulty in concentrating and mild mood disturbance; 2) mild chronic toxic encephalopathy, in which the exposed are diagnosed with abnormalities on neuropsychological tests; and 3) severe toxic encephalopathy, in which the exposed present with dementia- like symptoms that are often irreversible (WHO, 1985). Addressing CNS symptoms associated with PCE exposure at sub-clinical levels is important for multiple reasons. If neurotoxicity is caught early, symptoms may be reversible (Echeverria, White, & Sampaio, 1995). In addition, CNS symptoms, particularly memory loss and visual impairment, can affect the quality of life of workers and can negatively impact the safety of workers due to greater risk for injury (Echeverria et al., 1995).

CNS effects can occur at PCE exposure levels below the current Federal Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 100 ppm time weighted average (TWA) over a typical eight hour workday (OSHA, 2015). While the toxic effects of PCE exposure on the CNS and other body systems have long been recognized, the PEL has yet to change. The purpose of this paper is to understand effects of PCE exposure at levels below 100 ppm on the CNS through the review of current literature. The implications of the review's findings may be applied by occupational health practitioners (OHPs) not only in clinical practice, but also as advocates for policy changes that better protect workers.

Method

Search criteria for this literature review included original research of neurotoxic symptoms associated with sub-PEL PCE exposure in humans and articles written in English. Studies that examined the effects of PCE exposure at air concentration levels below 100 ppm were included in this review. Three search engines were used to identify articles: PubMed, Web of Science and PsycInfo. An initial PubMed search of "*Perchloroethylene AND Central Nervous System*" located only 21 studies. Therefore, a broad search with the MESH terms "*Perchloroethylene AND exposure*" was conducted, yielding 261 articles in PubMed, 318 articles in Web of Science, and 14 articles in PsycInfo. Thirteen articles met the search criteria of this review. Excluded studies focused on exposure assessment or reduction in exposure, cancer outcomes, other health outcomes, meta-analysis or reviews, mixed-solvent exposures, cohort mortality studies, opinion or economic analysis and general properties of PCE. Additionally, reviewing references of included studies identified two articles. A total of 15 articles met the search criteria and were included in this review.

Results

A summary of 15 studies is provided in Table 1. Of the 15 articles, three studied community exposures (Altmann, Neuhann, Kramer, Witten, & Jermann, 1995; Schreiber et al., 2002; Storm et al., 2011), nine studied occupational exposures (Cai et al., 1991; Cavalleri et al., 1994; Echeverria et al., 1995; Ferroni et al., 1992; Gobba et al., 1998; Lauwerys, Herbrand, Buchet, Bernard, & Gaussin, 1983; Nakatsuka et al., 1992; Seeber, 1989; Sharanjeet, Mursyid, Kamaruddin, & Ariffin, 2004), and three were experimental chamber studies (Altmann, Wiegand, Bottger, Elstermeier, & Winneke, 1992; Stewart, Baretta, Dodd, & Torkelson, 1970; Stewart et al., 1977). Community sources of PCE exposure were from PCE released into the air during the dry-cleaning process. Occupational exposures to PCE occurred in dry-cleaning facilities. Experimental studies exposed volunteers to PCE vapors in experimental chambers. CNS toxicity studied in the reviewed literature included visual impairment, dizziness, problems with balance and motor-coordination, and attention and memory deficits. More detailed information on each CNS toxicity symptom follows. Table 2 presents an overview of the effects of PCE exposure on selected CNS toxicity symptoms.

Visual Impairment

Visual impairment is identified as the most sensitive indicator of a neurological deficit from solvent exposure (Cavalleri et al., 1994). Eight studies (Altmann et al., 1995; Altmann et al., 1992; Cavalleri et al., 1994; Gobba et al., 1998; Nakatsuka et al., 1992; Schreiber et al., 2002; Sharanjeet et al., 2004; Storm et al., 2011) examined visual impairment in PCE exposed populations using three different measures: visual evoked potential (VEP) (Altmann et al., 1995; Altmann et al., 1992), visual contrast sensitivity (VCS) (Schreiber et al., 2002; Storm et al., 2011) and color vision deficits (Cavalleri et al., 1994; Gobba et al., 1998; Nakatsuka et al., 1992; Schreiber et al., 2002; Sharanjeet et al., 2004).

The VEP test measures the amount of time needed to transmit a visual stimulus from the eye to the brain (Creel, 2014). Of the two studies (Altmann et al., 1995; Altmann et al., 1992) that measured VEP, one experimental study (Altmann et al., 1992) found a significant change in VEP associated with PCE exposure. Altman et al. (1992) examined VEP in 28 volunteers exposed to either 10 ppm or 50 ppm PCE in a chamber for 4 hours/day for four days and found a significant increase in latency in VEP in the 50 ppm group. In another cross-sectional study of 37 community volunteers, no significant difference in VEP scores was found among residents in apartments directly above or next to a dry-cleaning establishment and their unexposed counterparts (Altmann et al., 1995).

VCS refers to the ability to differentiate between patterns or luminance in static images (Storm et al., 2011). Two cross-sectional studies examined VCS among residents in buildings co-located with dry-cleaning facilities and found significant associations between PCE exposure and decreased VCS (Schreiber et al., 2002; Storm et al., 2011). Storm et al. (2011) found that children residing in buildings with dry-cleaning facilities experienced decreased VCS at the spatial frequency of 12 cycles per degree significantly more frequently than children residing in apartments without dry-cleaning facilities (OR=2.64, 95% CI 1.41-5.52); a dose-response was also noted. However, they found no significant difference in VCS scores among adults (Storm et al., 2011). Schreiber et al. (2002) also found VCS to be impaired across all cycles per degree ($p<0.001$) in an exposed group of 17 residents and 9 daycare workers compared to the non-exposed group. The researchers suggested that VCS deficits may be irreversible because VCS scores were still lower in the exposed daycare worker group despite the fact that the co-located dry-cleaning facility ceased PCE use six weeks prior to VCS testing (Schreiber et al., 2002).

Color vision is often one of the first indicators of toxic optic neuropathy caused by chronic exposure to solvents (Cavalleri et al., 1994). Three of five studies showed significant associations between PCE exposure and color vision loss (Cavalleri et al., 1994; Gobba et al., 1998; Sharanjeet et al., 2004). In a longitudinal study of 33 dry-cleaners, Gobba et al. compared Color Confusion Index (CCI) between two groups by different levels of PCE exposure over time. Both groups had an elevated CCI at baseline (elevated scores indicate poorer color vision). For the group that had lower PCE exposure at baseline but experienced an increase in PCE exposure at the two-year follow-up (1.67 ppm and 4.3 ppm, respectively), the mean CCI score significantly increased at the follow-up (1.16 vs. 1.26; $p < 0.01$). For the group that had higher PCE exposure at baseline but decreased PCE exposure at the follow up (2.9 ppm to 0.7 ppm), there was no change in CCI scores. The authors concluded that color vision loss may be irreversible or there was an insufficient reduction in exposure (Gobba et al., 1998).

Three cross-sectional studies (Cavalleri et al., 1994; Nakatsuka et al., 1992; Sharanjeet et al., 2004) compared color-vision between dry-cleaners and their matched, unexposed controls. Cavalleri et al. (1994) found a higher mean CCI score in the exposed group compared to their un-exposed counterparts in a study of 70 workers (1.14 vs. 1.08; $p=0.025$). The researchers speculated that subclinical color vision loss may be associated with PCE exposure levels as low as 5-11 ppm (Cavalleri et al., 1994). Sharanjeet-Kaur et al. (2004) examined color vision using two tests of Lanthony D15 scores and Farnsworth 100 Hue tests in their sample of 44 workers. Color vision deficits were detected in 42.9% of dry-cleaners with PCE exposure by the Lanthony D-15 tests and 92.9% by the Farnsworth 100 Hue test, while no deficits were found in the unexposed group (Sharanjeet et al., 2004). On the other hand, Nakatsuka et al. (1992) did not find any significant difference in CCI scores between exposure groups in their sample of 184 workers. This finding may be because they used Lanthony's new color test, which may not be sensitive to subclinical changes (Cavalleri et al., 1994).

Balance, Motor-Coordination and Dizziness

A total of seven studies measured vestibular-motor manifestation of CNS toxicity (Altmann et al., 1995; Altmann et al., 1992; Cai et al., 1991; Echeverria et al., 1995; Ferroni et al., 1992; Stewart et al., 1970; Stewart et al., 1977). Of these studies, six measured balance or coordination (Altmann et al., 1995; Altmann et al., 1992; Cai et al., 1991; Ferroni et al., 1992; Stewart et al., 1970; Stewart et al., 1977) and three measured dizziness (Cai et al., 1991; Echeverria et al., 1995; Stewart et al., 1977).

In their experimental chamber study, Stewart et al. measured balance using a modified Romberg test in 17 healthy volunteers exposed to 100 ppm PCE for seven hours a day over a five-day period (Stewart et al., 1970). Overall 17.6% of participants lost balance at post-exposure and 25% complained of slight lightheadedness. In a double-blind experimental study, Stewart et al. (1977) studied nine volunteers exposed to PCE levels between 25-100 ppm for 11 weeks and found reports of dizziness increased with PCE exposure. While balance was not affected by PCE exposure, significant impairment in motor coordination was found in volunteers exposed to 100 ppm PCE by the Flanagan Coordination test (Stewart et al., 1977).

Altmann et al. assessed motor coordination using the finger-tapping test and a computer game in which participants were asked to trace objects on a screen in cross-sectional and experimental studies (Altmann et al., 1995; Altmann et al., 1992). Only their experimental study found a significant decrement in coordination scores as measured by the tracing task. Both the 10 ppm and 50 ppm PCE exposure group scores improved over the four-day study period (representing a learning effect), but the 10 ppm group showed significantly greater improvement, suggesting that the motor learning improvement from practice effects was poorer for the group that had higher exposure to PCE (Altmann et al., 1992). Ferroni et al.'s (1992) cross-sectional study of 90 workers found that exposed workers had impaired coordination and psychomotor function as evidenced by significantly lower finger-tapping scores.

Two cross-sectional studies (Cai et al., 1991; Echeverria et al., 1995) measured dizziness or symptoms related to dizziness in dry cleaners. In Cai et al.'s (1991) study of 125 workers subjective symptom reports of lack of coordination or balance (e.g., drunken feeling, floating sensations) and dizziness were significantly higher in the exposed group (11-45%) compared to the unexposed (0-12%). Echeverria et al.'s (1995) study of 65 workers also found that there was a statistically significant increase in the mean 3-month, solvent-related dizziness severity score with higher PCE exposure.

Attention and Memory Deficits

Seven studies used a variety of methods to examine the association between PCE exposure and attention and memory deficits (Altmann et al., 1995; Altmann et al., 1992; Cai et al., 1991; Echeverria et al., 1995; Ferroni et al., 1992; Lauwerys et al., 1983; Seeber, 1989). Attention was measured by reaction time, logic, and vigilance. Reaction time tests measured the lapsed time between a stimulus and a response. Logic tests measured one's ability to focus and concentrate on the task at hand. Vigilance tests measured the ability to maintain concentration for an extended period of time.

Five cross-sectional studies measured attention and memory loss in dry-cleaners exposed to PCE (Cai et al., 1991; Echeverria et al., 1995; Ferroni et al., 1992; Lauwerys et al., 1983; Seeber, 1989). Cai et al.'s (1991) study of 125 workers found a higher prevalence of self-reported memory loss among exposed dry-cleaners compared to workers at the same factory who were not exposed to solvents (39% vs. 14.5%, $p<0.01$). Lauwerys et al.'s (1983) study of 59 workers also found that self-reported memory loss was more prevalent in the exposed group

(27% vs. 9%), but no associations were found between PCE exposure and attention or reaction time. Likewise, Echeverria et al.'s (1995) study of 65 workers found no difference in attention between low and high exposure groups, but visual memory scores, as measured by pattern memory and visual reproductions, were significantly lower in the high-exposure group. In contrast, Seeber's (1989) study of 185 workers found that workers in the exposed group had impaired attention, as measured by a cancellation task, but no difference in memory. Ferroni et al. (1992) also found significant associations between PCE exposure and impairment in attention using a battery of tests from the Swedish Performance Evaluation System in their study of 90 female workers. Vigilance, as measured by a shape sorting test, was lower, and reaction time was prolonged in the exposed group.

Altmann et al. (1992) conducted comprehensive neurobehavioral evaluations to measure reaction time, vigilance and memory with 28 participants in their experimental study. They found a trend for a longer period of response latency in participants exposed to 50 ppm PCE compared to those exposed to 10 ppm PCE (p=0.09) (Altmann et al., 1992). Both groups had improvements in vigilance, measured using continuous performance test (CPT) scores, at the end of the four-day trial (as expected due to learning over time),compared to baseline; however, the 10 ppm group showed a greater improvement (Altmann et al., 1992). No differences in visual memory were found between the two groups exposed to PCE. In their later cross-sectional study, Altmann et al. (1995) found significant differences in memory between an exposed group of 14 apartment residents who lived next to or above dry-cleaning facilities compared to their 23 age- and sex- matched controls. The exposed group had poorer visual memory, as measured using the Benton visual retention test score, and also a prolonged reaction time after controlling for age, gender and education (Altmann et al., 1995). The exposed group also performed poorer than the unexposed group on the CPT, indicating decreased ability to remain vigilant (Altmann et al., 1995).

Discussion

This review evaluated 15 studies that examined the association of exposure to PCE at or below the PEL of 100 ppm with CNS toxicity as measured by visual impairment, attention and memory deficits, dizziness and impaired motor-coordination. Of the 15 studies reviewed, 14 found positive associations between PCE exposure and at least one CNS toxicity symptom. The majority of the reviewed studies found that CNS toxicity symptoms were significantly associated with PCE exposure at levels below 50ppm. Six of the eight studies on visual impairment (Altmann et al., 1992; Cavalleri et al., 1994; Gobba et al., 1998; Schreiber et al., 2002; Sharanjeet et al., 2004; Storm et al., 2011), four of the six studies on memory impairment (Altmann et al., 1995; Cai et al., 1991; Echeverria et al., 1995; Lauwerys et al., 1983), four of the six studies on attention deficits (Altmann et al., 1995; Altmann et al., 1992; Ferroni et al., 1992; Seeber, 1989), and all three studies on dizziness (Cai et al., 1991; Echeverria et al., 1995; Stewart et al., 1977) found significant associations with PCE exposure. Two studies also indicated that changes in vision may persist even after PCE exposure was reduced or eliminated (Gobba et al., 1998; Schreiber et al., 2002). Taken together, overall evidence indicates that CNS functions can be impaired by exposures to PCE even below the PEL, some of which may be permanent.

Limitations in the Reviewed Literature

This review identified several methodological limitations that may be considered when determining the collective weight of evidence of these studies. Limitations are related to study design, study populations, exposure and outcome measurement, and lack of control for variables that may influence exposure or symptom development.

Study design and sample. Eleven of the 15 studies reviewed were cross-sectional, which limits the ability to establish causation. Cross-sectional studies can provide a snapshot of current exposure levels but are unable to account for past exposure. Because some health effects of PCE exposure are likely irreversible, it is unclear whether the CNS effects noted were related to current exposure or prior exposure. Cross-sectional studies are vulnerable to unrepresentative sampling caused by selection and healthy worker effect bias. Selection bias (specifically non-response bias) occurs because only participants who want to be in the study are included in the study. These participants may have different traits than those who do not participate. The healthy worker effect can lead to underestimation of the prevalence of disease because only workers healthy enough and able to tolerate the work environment are included in occupational studies.

The three experimental studies included in this literature review examined only short-term exposures ranging from four days to eleven weeks and thus could not be applied to chronic PCE exposure below the PEL. One longitudinal study followed workers over two years, but researchers obtained exposure levels only at the beginning and end of the study period so the reader does not know how exposure may have varied over the two- year period (Gobba et al., 1998). Finally, with few exceptions, study sample sizes were small (N= 9 to 381), further decreasing ability to detect associations between PCE exposure and CNS deficits.

Outcome and exposure assessment. Regulatory decisions often rely on reviewing the weight of evidence established by comparing results across studies (Goodman et al., 2010). Therefore, it is important to use similar outcome and exposure assessments across studies (Goodman et al., 2010). This review found variations in definitions and instruments used to measure CNS symptoms across studies, making it difficult to compare findings. No standardized measure was used when evaluating balance, coordination and dizziness. For example, Cai et al. (1991) measured the prevalence of "floating sensation" and "drunken feeling," which may be comparable to balance, coordination or dizziness. Three studies used self-report measures of memory loss but did not provide any information about reliability or validity of their measure (Cai et al., 1991; Lauwerys et al., 1983; Stewart et al., 1970). In addition, selection of tests may impact findings. For example, in Sharanjeet- Kaur et al.'s (2004) study the number of workers identified with color vision deficits differed depending on which test was used.

As for PCE exposure, most studies provided objective exposure estimates based on air sampling, but comprehensive estimation of cumulative exposure was limited. Seven studies examined the duration of exposure (Altmann et al., 1992; Cavalleri et al., 1994; Echeverria et al., 1995; Ferroni et al., 1992; Lauwerys et al., 1983; Sharanjeet et al., 2004; Storm et al., 2011), but only one study found an association between memory loss and exposure duration as measured by time in industry (Echeverria et al., 1995). The negative findings may be because researchers did not account for PCE levels changing over job tenure. Change in exposure is an important consideration, as PCE exposure in some dry-cleaning facilities may have decreased since the introduction of closed-loop machines and condensers (Gold, De Roos, Waters, & Stewart, 2008). One study that evaluated a lifetime cumulative index for the amount of time working in each task suggested that a minimum of three years may be necessary to present with chronic CNS toxicity symptoms (Echeverria et al., 1995).

Dose response. Dose-response refers to the change in likelihood of an adverse health effect occurring as the exposure level changes (EPA, 2012b). Establishing a dose response is essential in characterizing the risks associated with exposure, which is then used to set regulatory exposure limits (EPA, 2012b). This is based on reviewing results across studies and then using extrapolation techniques to estimate risk (EPA, 2012b). Of the studies reviewed, only two studies observed a dose response, one of which observed a dose response for dizziness (Echeverria et al., 1995) and one for VCS (Storm et al., 2011). Other factors besides dose may impact dose-response. For example, how one reacts to PCE exposure may have more to do with the rate of concentration change than the concentration level itself (Kjellstrand, Holmquist, Jonsson, Romare, & Mansson, 1985; Warren, Reigle, Muralidhara, & Dallas, 1996). Different ethnic groups may metabolize PCE differently (Jang, Droz, & Berode, 1997), but none of the studies took ethnicity into account. Lack of dose response in most studies may be related to the non-linear relationship between metabolism of PCE and CNS impairment, which can perhaps be remedied by more sophisticated pharmacodynamic models (Guyton et al., 2014; Warren et al., 1996) that do not assume a linear response between PCE exposure and symptoms. Finally, lack of dose response may be related to how exposure was classified in the studies. There was no rationale given as to how low, medium and high exposure groups were created in many of the studies. Therefore, it is important to establish a threshold exposure level at which CNS symptoms appear (Seeber, 1989).

Control of confounding factors. Neurologic symptoms such as headaches and dizziness are nonspecific and can be associated with other factors, including uncomfortable physical environments (e.g., working in a hot room) and psychosocial stress. As stress has been associated with learning and memory deficits (Stenfors, Hanson, Oxenstierna, Theorell, & Nilsson, 2013), working in a stressful industry may impact neurobehavioral performance. Workers may also be more exposed to PCE when they have an increased workload or a more physically demanding role, due to increased air exchange rate (Fernandez, Guberan, & Caperos, 1976). However, such potential factors were not considered in the reviewed occupational studies.

Implications for Policy, Practice, and Research

Policy implications. The current federal OSHA PEL of 100 ppm TWA was developed based on the 1968 American Council of Governmental Industrial Hygienist (ACGIH) recommendations (National Institute for Occupational Safety and Health [NIOSH], 1987). ACGIH has since changed their recommendations to 25 ppm and the National Institute for Occupational Safety and Health set the recommended exposure level to the lowest feasible exposure level (OSHA, 2015). In 1989, OSHA attempted to decrease the PEL to 25 ppm; however, the United States Appeals Court remanded the new PEL, citing concerns from industry that the cost of compliance would be burdensome for dry-cleaning establishments (American Federation of Labor and Congress of Indus. Organizations v. Occupational Safety and Health Admin, 1992). The unions did not support the PEL change because they believed that the proposed PEL of 25 ppm was not protective enough (American Federation of Labor and Congress of Indus. Organizations v. Occupational Safety and Health Admin, 1992). While Federal OSHA could not change PEL, California OSHA has since decreased the PEL to 25 ppm (OSHA, 2015).

Technological advances such as dry-to-dry machines have helped to decrease PCE exposure in the dry-cleaning industry. However, workers in other industries may not benefit from technological advances and may still be exposed to high PCE levels. Furthermore, technological advances may not fully prevent PCE air emission. One systematic analysis estimated that the PCE exposure level among dry-cleaner workers using dry-to-dry machines was approximately 10 ppm TWA (Gold et al., 2008). Yet this review found evidence that subclinical symptoms of neurotoxicity from PCE can occur at less than 10 ppm (Cavalleri et al., 1994; Gobba et al., 1998; Schreiber et al., 2002; Storm et al., 2011). Given new technological advances, the dry-cleaning industry has several options to use safer cleaning methods, and the U.S. EPA mandates the use of new machines that emit less PCE into air. Therefore, compliance with a more protective PEL can no longer be considered burdensome. Other options for reducing PCE exposure is incentivizing use of safer alternatives, such as wet cleaning.

Without national leadership, little incentive exists for the industry to adapt more protective practices. Recognizing this lack of incentive, Federal OSHA is currently reviewing its overall approach to managing occupational exposures to chemicals such as PCE that can cause adverse health effects due to long-term exposures (OSHA, 2014). In 2014 OSHA submitted a request for information on how to incorporate new approaches to protect workers from chemical exposures (OSHA, 2014). Therefore, it is crucial to engage in dialogue regarding lowering the PEL and considering additional measures such as exposure banding and control banding to adequately classify chemicals and improve safety guidelines for occupational chemical exposure.

Practice considerations. Because the dry-cleaning industry mainly consists of small family-run businesses, many employees of dry-cleaning facilities may not have access to occupational health resources. Therefore, providing occupational health services to this population may be especially challenging. Results of this literature review indicate a need for practice considerations for OHPs who provide care to workers in larger dry-cleaning facilities and other industries that use PCE. For exposure assessment, OHPs need to conduct a more in-depth assessment for PCE exposure. Components to consider adding to the assessment include a comprehensive work history detailing time spent doing each task, duration of solvent exposure, workload, PPE use, engineering controls available at the worksite and factors that may increase risk for neurobehavioral deficit (i.e. alcohol consumption, other solvent exposure, stress, etc.). For clinical assessment, it is important that OHPs select tests that are sensitive to subclinical signs and symptoms. Common symptoms that can be assessed include VCS deficits, color-vision impairment, memory impairment (Altmann et al., 1995; Cai et al., 1991; Echeverria et al., 1995; Lauwerys et al., 1983) and recent complaints of dizziness (Cai et al., 1991; Echeverria et al., 1995; Stewart et al., 1970; Stewart et al., 1977). Prevention and early detection are crucial given the findings that some symptoms of CNS toxicity such as visual impairment may be permanent. Furthermore, OHPs can provide education on safe work practices to further reduce PCE exposure and identifying early signs of CNS toxicity. If a worker is exhibiting CNS symptoms, it is important to provide comprehensive care to decrease exposure. Depending on severity of symptoms OHPs may consider some of the following options: 1) removing the individual from exposure and contact the Poison Control for immediate assistance as work restrictions may be necessary, 2) referring the individual for neuropsychological testing to document any impairments, 3) informing the worker of their right to make an anonymous complaint to OSHA regarding their symptoms and exposures, 4) encouraging the employer to seek free consultation from OSHA Consultation Services, 5) requesting for the local health department to provide sampling data of neighborhood air quality and 6) filing a workers' compensation claim , with a request for industrial hygienist to assess the worksite.

Research implications

The current knowledge on long-term or potentially irreversible effects of PCE exposure is limited. Given evidence from retrospective cohort community studies, the effects of PCE may be long-term. Two studies of the same population of adults who were exposed to PCE in the water supply during their prenatal period and early childhood found an association between exposure and VCS deficits (Getz et al., 2012) and memory and attention deficits (Janulewicz et al., 2008) that persisted into adulthood. While the evidence of long-term health effects is limited in occupational exposure studies, two studies found potentially irreversible vision impairments (Gobba et al., 1998; Schreiber et al., 2002). The effects of PCE of the CNS may also be latent: Two studies not included in this review found workers exposed to PCE were at increased risk for Parkinson's disease (Goldman et al., 2012) and "non-malignant disease of the nervous system" (Silver et al., 2014).

Several factors that can impact PCE exposure were not evaluated in the existing literature. For example, while air sampling did occur in most occupational studies, no studies accounted for use of personal protective equipment, personal protective behavior, or administrative controls that may decrease exposure. Differences in personal protective equipment use and personal protective behavior may result in workers being exposed to varying PCE levels even though they work in the same environment. Personal protective equipment is often not used or used incorrectly (Whittaker & Johanson, 2013). Administrative controls may limit the amount of time that workers spend working on a high exposure task, so it is important to account for the percent of time working in each task, as Echeverria et al. (1995) did.

Finally, all of the occupational studies included in this literature review were among dry cleaners, although workers in other industries such as PCE manufacturing, degreasing operations, and refrigerant industry are also exposed. There may be differences by occupation in exposure routes, duration of exposure and environmental factors that make workers more susceptible. Therefore more research is needed in other occupational settings.

Conclusion

In conclusion, findings in this literature review indicate that CNS toxicity symptoms from PCE exposure can occur at levels well below the current PEL of 100 ppm. Furthermore, some evidence suggests CNS toxicity symptoms such as visual impairment may be irreversible. These findings indicate a need to develop better protective measures for workers exposed to PCE. To strengthen the current body of literature, a clear dose-response needs to be established, particularly through longitudinal studies using validated and objective measures. Better measures of duration of exposure are needed to adequately determine true exposure over time. More emphasis should also be placed on long-term health effects. In occupational studies, research should include workers in other industries such as workers in degreasing operations and also address other occupational factors, including stress and work environment that can impact both exposure and CNS toxicity symptoms. Future research with stronger study designs and methods addressing the gaps noted will help policy makers to establish a lower PEL as well as to develop best practice guidance for protection of workers. Finally, OHPs should assess for sub-clinical impairments using tests that are sensitive enough to detect symptoms early, provide multidisciplinary case management for PCE-exposed workers and advocate for a protective Federal OSHA PEL.

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Table 1

Summary of Reviewed Literature on CNS Toxicity Symptoms Associated with PCE Exposure Below 100 parts per million

Author (year), country	Study Design	Sample	Perchloroethylene Exposure	Outcome (CNS effects and measures)	Main Findings
Sharanjeet-Kaur (2004) Malaysia	Cross Sectional	° Employees in 3 dry-cleaning premises using PCE (n=14) and 2 plastic manufacturing factories using petroleum derivatives (n=39). Sites randomly selected ° Two age-matched control groups without occupational exposure (n=56)	° PCE and petroleum derivatives (polyethylene and polystyrene) ° Exposure determined by work-site	Vision ° Ishihara plates ° Lanthony D-15 test ° Farnsworth Munsel (FM) 100 Hue tests with calculated total error scores • Tests performed twice on different days; the second results used for analysis	Vision ° Ishihara: no cases in any group ° Lanthony D-15: 43% in dry-cleaning workers had color vision deficit compared to, 21-31% in plastic factory workers, 0% in controls ° FM 100 Hue: 93% in dry-cleaning workers had color vision deficit compared to, 51-65% in plastic factory workers, 0% in controls ° No correlation between employment duration and total error scores
Gobba et al. (1998) Italy	Longitudinal	° 33 dry-cleaners employed at 2 facilities divided into two groups based on exposure level ° Group A (n=19) ° Group B (n=14)	° PCE air concentration measured by personal passive samplers ° Group A: Mean PCE? 1.7ppm at baseline and 4.3ppm at year 2 ° Group B: 2.9ppm at baseline and 0.7ppm at year 2	Vision ° Lanthony D-15 to calculate color confusion index (CCI)	Vision ° Both groups had color vision deficits at baseline ° Group A: Color vision worsened (baseline CCI 1.16 to 1.2 at follow up (p<0.01) ° Group B: No changes in color vision (CCI remained at 1.15 at baseline and follow up)
Echeverria et al. (1995) United States	Cross-Sectional	•65 dry-cleaners from 23 shops (17 shops with transfer cleaner machines and 6 shops with dry-to-dry machines)	•PCE air concentration sampled for 15 minutes within breathing zones of a clerk, a presser, and an operator in 19 of	Memory •Visual Reproductions Subtest •Wechsler Memory Scale •Pattern Memory •Pattern Recognition	Memory • visual reproduction: 17.7% difference in scores (p=0.03) and 11.5% difference in pattern memory score (p=0.02) between high and low exposure groups; 5.1% difference in pattern recognition score (p=0.04) between high and low exposure groups

Pce= Perchloroethylene; ppm= parts per million; HE= High Exposure Group; ME= Medium Exposure Group; LE= Low Exposure Group; yr= years; wks= weeks; ms=milliseconds (+)= statistically significant p<.05

		•Low-exposure group cashiers (n=24) were age and education matched to high exposure group (n=23) •response rate 18%	the 23 shops. • breath PCE concentration within 2 minutes post-exposure in solvent-free zone •PCE chronic index of exposure (job title X duration of employment)	Attention •digit span • trail making test Motor coordination •Symbol-Digit matching Dizziness •Symptoms checklist	Attention •No significant difference in digit span and trail making test scores between exposure groups Motor coordination •No significant difference is symbol matching scores between exposure groups Dizziness •1.5% difference in solvent related dizziness scores between high and low exposure groups (p=0.04). •Dose response noted for dizziness only • at least 3 years for symptoms to develop
Cavalleri et al. (1994) Italy	Cross-Sectional	•35 dry-cleaners •35 healthy controls who were not exposed to solvents (matched for Sex, age, alcohol consumption and cigarette smoking)	•PCE air concentration at worksite measured using personal passive monitor in breathing zone over an 8-hour shift.	Color Vision •Lanthony D-15 to measure color confusion index (CCI)	Color Vision •Color vision deficits noted in dry-cleaners (CCI= 1.14 vs. 1.08 in controls; p=-.025) •Dose response noted. Dry-cleaner operators has higher CCI than pressers (1.2 vs. 1.1; p=0.007) •Correlation between PCE levels and CCI (r=0.52, p<0.01) •Duration of PCE exposure not correlated with CCI
Ferroni et al. (1992) Italy	Cross-sectional	•60 female dry-cleaner shop workers •30 controls from industrial cleaning plant. Matched on Age, sex and vocabulary scores.	•PCE levels in blood •PCE air concentration during random 4 hour time period	Attention •simple reaction time •digit symbols •shape comparison test Motor Coordination •Finger tapping dominant and non-dominant hand	Attention • Simple reaction time was delayed for dry-cleaners compared to controls (259 vs. 235; p<0.001) vigilance (635 vs. 589, p<0.005) Motor coordination •finger tapping scores lower among dry-cleaners indicating deficit (p<0.01) •Duration of exposure and PCE levels were not associated with outcomes

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Nakatsuka et al. (1991) Japan	Cross-sectional	•261 exposed: - 174 toluene paint production plant workers - 23 TCE/PCE manufacturing plant workers - 64 PCE dry-cleaners •120 age and sex matched controls who were clerical workers at same factories	•Time weighted average PCE air concentration in breathing zone measured using diffusive sampling	Color Vision •Lathony's new color test (general screening) •Ishihara's color vision test for diagnosing red/ green color vision loss if workers did not pass first test	Color Vision •Only six cases of color vision impairment identified, all of which were red/ green color vision loss, indicating color vision loss was hereditary and not related to exposure.
Cai et al. (1991) China	Cross-sectional	•56 workers from three dry-cleaning workshops within factories •69 controls matched for age and sex from same factories who did not have exposure	•Passive sampling used to measure PCE air concentration at worksite	Memory, dizziness and Coordination •Symptoms experienced in past three months •Symptoms experienced while at work (no time frame) •questionnaire asked by physician.	Memory, dizziness and Coordination (dry cleaners vs. controls) •3-month prevalence: heavy feeling in head (16.1% vs. 1.4%, p<0.01), drunken feeling (10.7% vs. 0, p<0.05), forgetfulness (39.3% vs. 14.5%, p <0.01) • Symptoms at work: Dizziness (44.6 vs. 11.6; p <0.001), Floating sensations (23.2 vs. 5.8%; p<0.01), drunken feeling (17.9% vs. 0; p<0.001), heavy feeling in head (19.6 vs. 1.4 p<0.001) •No statistically significant dose- response between symptoms and PCE exposure level
Seeber et al. (1989) Germany	Cross-sectional	•101 dry-cleaners •84 controls (sales personnel and receptionists)	•PCE air concentration measured in 30-minute intervals and throughout day at worksite.	Motor coordination •tapping and aiming •choice reaction test Attention •Cancellation task •digit symbol Perceptual speed Memory •Digit Span	Motor coordination •No significant difference in motor coordination test scores between exposure groups Attention •cancellation task score lower in exposed group (103 vs. 98.2; p<0.01) •lower digit symbol score in exposed group (48.1vs. 41.1; (p<0.01). •Exposed group required Increased time required to identify similar objects (perceptual speed (0.42s vs. 0.57s; p<0.01) Memory

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					•No significant differences in digit span scores between exposure groups •No dose response between exposure and symptoms
Lauwerys et al. (1983) Belgium	Observational	•26 dry-cleaner workers from 6 shops •33 controls from chocolate factory and health services department (matched for age and gender)	• air PCE concentration measured by personal air sampler (one day) and 3M organic solvent badge •blood concentration •urine test (before and after work) •breath sample (before work)	Memory Loss •22item subjective symptom survey Attention •sustained attention •visual reaction time • critical flicker fusion	Memory Loss •increased prevalence of memory loss in exposed (27% in exposed vs. 11% control) Attention •None of the attention scores significantly differed between exposure groups •no relationship with duration of exposure and symptoms
Altmann et al. (1992) Germany	Experimental	Young, male volunteers recruited from unemployment office and university exposed to PCE in chamber •50ppm exposure (n=16) •10ppm exposure (n=12)	• PCE levels controlled by gas chromatograph •exposed to PCE 4 hours a day x 4 days •blood sampling 3x/day and baseline, after study -	Visual Impairment • visual evoked potential (VEP) test (daily) Motor coordination •finger tapping •eye-hand coordination Attention •reaction time •continuous performance test (CPT) •symbol digit test Memory •Benton visual retention •pattern recognition •digit span	Visual impairment •Increased delay in VEP responses in high exposure group Motor Coordination •Lower Eye-hand coordination scores in exposed group (p=0.05) Attention •Delayed reaction time in 50ppm group (p=0.09) •CPT- scores improved in both groups, higher degree of improvement in 10ppm group (p=0.04) Memory •No significant difference in memory test scores between exposure groups. •No symptoms were associated with duration of PCE exposure

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Stewart et al. (1977) USA	Experimental	•9 volunteers	•exposed to 25-100ppm PCE, valium and alcohol 5.5 hours/day x11 weeks	Balance/ coordination •Flanagan, Michigan hand eye, rotary rotation tests •Modified Romberg test Dizziness •Subjective symptom Questionnaire	Balance/ coordination •only Flanagan test showed coordination deficit among high exposure group. •No difficulty balancing Dizziness •Mean dizziness score increased as PCE exposure increased.
Stewart et al. (1970) USA	Experimental	•17 volunteers for 7 hour experiment •5 volunteers exposed for 5 days.	• PCE concentration in chamber 100ppm x7 hours •5 volunteers exposed to PCE 7hr/day x 5days.	Balance/ coordination •Modified Romberg test •Subjective symptom questionnaire before and after time in chamber.	Balance/ coordination •40% felt sleepy; 25% difficulty speaking; 17% difficulty balancing during or after PCE exposure •tolerance to effects of PCE increased with time
Storm et al. (2011) United States	Cross-sectional	•Exposed: 54 adults and 50 children from 24 apartments co-located with dry-cleaners using PCE •Controls: 47 adults and 54 children residing in buildings not co-located with dry-cleaning facility	•Breath PCE •Blood PCE •Organic vapor monitors measured PCE air concentration in home for 24 hours	Visual Impairment •functional acuity contrast test (FACT) measured visual contrast sensitivity (VCS) •Conducted by optometrist. Each eye tested separately	Visual Impairment •children in the exposed group were 2.64x (95% CI 1.4-5.5) likely to experience VCS impairment in their weaker eye at the spatial frequency of 12 cycles per degree (cpd). Dose response only noted at 12 cpd •VCS was not associated with duration of exposure
Schreiber et al. (2002) United States	Cross-sectional	•17 residents (13 adults/4 children) from 2 buildings co-located with dry-cleaner; 17 age/ sex matched controls recruited from public health department employees •9 daycare workers working in building co-located with dry-cleaner and 9 age/ sex	•Urine PCE •Breath PCE •Indoor air and personal air PCE measured using passive organic vapor sampling devices •PCE measured at dry-cleaner site co-located with daycare-6 weeks before VCS testing	Vision •functional acuity contrast test measured visual contrast sensitivity (VCS) •Lanthony D- 15 Hue test to measure color confusion index (CCI)	Vision • Exposed group had decreased VCS than controls in all spatial frequencies ($p<0.001$) •In daycare workers, VCS scores remained lower than control groups scores, even though dry-cleaner ceased operations 6 weeks prior, indicating deficit has not resolved •No significant difference in mean CCI scores between exposure groups •No dose response between visual impairment and PCE exposure

Pce= Perchloroethylene; ppm= parts per million; HE= High Exposure Group; ME= Medium Exposure Group; LE= Low Exposure Group; yr= years; wks= weeks; ms=milliseconds (+)= statistically significant $p<.05$

		matched controls recruited from participant acquaintances and unexposed daycare workers			
Altmann et al. (1995) Germany	Cross-sectional	•14 residents lived above or below dry-cleaning facility and blood PCE>2ug •23 age/ sex matched healthy controls selected from a pool of employees a public health and environmental hygiene office.	•Blood PCE • PCE air levels concentration measured using passive samplers measured over 7 days	<u>Vision</u> • <u>visual evoked potential</u> <u>Motor Coordination</u> •finger tapping •eye-hand coordination <u>Attention</u> •reaction time •continuous performance test (CPT) <u>Memory</u> •Benton visual retention	<u>Vision</u> •no significant difference in VEP scores between exposure groups <u>Motor Coordination</u> •no significant difference in scores between exposure groups <u>Attention</u> •CPT-Increased time needed (370.4ms vs. 324.4; $p<0.05$) to accomplish given task in exposed group •Reaction time (ms) - prolonged in exposure group (306 vs. 255.4; $p<0.01$) <u>Memory</u> •Visual memory –less correctly identified visual stimuli in exposed (9.4 vs. 10.8; $p<0.05$)

Pce= Perchloroethylene; ppm= parts per million; HE= High Exposure Group; ME= Medium Exposure Group; LE= Low Exposure Group; yr= years; wks= weeks; ms=milliseconds (+)= statistically significant $p<.05$

Table 2

Review of Association between PCE exposure and CNS effects.

Author	Exposure Source	Mean PCE exposure (ppm)	Mean exposure duration	Memory loss	Attention	Balance	Dizziness	Motor-Coordination	Color Vision	Visual Evoked Potential	Visual Contrast Sensitivity
Storm et al. (2011)	Residential	0.5	7 yr LE 8.5yr HE								(+)
Sharanjeet et al. (2004)	Occupational	Not measured	6.7 yr						(+)		
Schreiber et al. (2002)	Residential	0.91	6 yr (median)						(-)		(+)
Gobba et al. (1998)	Occupational	Group A= 4.3 Group B= 0.7	na						(+)		
Altmann et al. (1995)	Residential	20.05	10.6 yr	(+)	(+)			(-)		(-)	
Echeverria et al. (1995)	Occupational	11.2 LE/ 23.2 ME/ 40.8 HE	3.4 yr LE/ 8.1 yr ME/ 20.2 yr HE	(+)	(-)		(+)	(-)			
Cavalleri et al. (1994)	Occupational	7.27	8.8 yr						(+)		
Altmann et al. (1992)	Experimental	50	4 hr/ day x4 days	(-)	(+)			(+)		(+)	
Ferroni et al. (1992)	Occupational	15	10.1 yr		(+)			(+)			
Nakatsuka et al. (1992)	Occupational	13	na						(-)		
Cai et al. (1991)	Occupational	20	3.1 yr	(+)		(+)	(+)				
Seeber (1989)	Occupational	12.3 LE 56.3 HE	11.7 yr LE 10.6 yr HE	(-)	(+)			(-)			
Lauwerys et al. (1983)	Occupational	20.8	6.4 yr	(+)	(-)						

Pce= Perchloroethylene; ppm= parts per million; HE= High Exposure Group; ME= Medium Exposure Group; LE= Low Exposure Group; yr= years; wks= weeks; ms=milliseconds (+)= statistically significant $p<.05$

Author	Exposure Source	Mean PCE exposure (ppm)	Mean exposure duration	Memory loss	Attention	Balance	Dizziness	Motor-Coordination	Color Vision	Visual Evoked Potential	Visual Contrast Sensitivity
Stewart et al. (1977)	Experimental	25-100	5.5 hr/ day x 11 wks			(-)	(+)	(+)			
Stewart et al. (1970)	Experimental	100	7 hr/ day x 1 or 5 days		(+)	(+)					

Pce= Perchloroethylene; ppm= parts per million; HE= High Exposure Group; ME= Medium Exposure Group; LE= Low Exposure Group; yr= years; wks= weeks; ms=milliseconds (+)= statistically significant p<.05

Chapter 3

Self-reported Central Nervous System Toxicity Symptoms in the Dry-cleaner Workforce: A Cross-sectional Study

ABSTRACT

Background: Organic solvent exposure can cause central nervous system (CNS) toxicity. Although exposure to organic solvents has decreased, dry-cleaning facility workers may still experience CNS toxicity symptoms.

Objectives: Determine prevalence and risk of CNS toxicity in a sample of dry-cleaners who primarily use dry-to-dry machines.

Methods: Secondary analysis of a cross-sectional survey of 180 dry-cleaners. ANOVA and Kruskal- Wallis test were used to determine predictors associated with CNS toxicity symptoms. Multinomial logistic regression analysis compared likelihood of symptom frequency between exposure groups.

Results: Nearly 24% of participants reported loss of visual perception, 18% reported dizziness, 14% reported memory loss and 13% reported tinnitus. Controlling for personal protective equipment use, high exposure group workers were 3.4 times (95% CI: 1.08-10.73) more likely to report loss of visual perception occurring “sometimes” compared to those in the low exposure group.

Conclusions: Further research of CNS toxicity in the dry-cleaner workforce is warranted.

Key Words: Central nervous system; tetrachloroethylene; solvents, dry-cleaners; visual impairment

INTRODUCTION

Organic solvents are substances that can extract materials that are not soluble in water. Given their unique cleaning properties, they are frequently used in cleaning industries, such as they dry-cleaning industry. The association between organic solvent exposure and neurotoxicity has been well established [1]. In 1985, the World Health Organization classified organic solvent-induced Central Nervous System (CNS) disorders into three categories: 1) Organic Affective Syndrome, in which the exposed complain of fatigue, memory impairment, irritability, difficulty in concentrating and mild mood disturbance, 2) Mild Chronic Toxic Encephalopathy in which the exposed are diagnosed with abnormalities on neuropsychological tests, 3) Severe Toxic Encephalopathy in which the exposed present with dementia- like symptoms that are often irreversible [2].

Within the dry-cleaning industry the most commonly used solvent is Tetrachloroethylene (PCE) with approximately 70% of dry-cleaners using PCE [3]. Substantial evidence of the carcinogenicity of PCE prompted the International Agency for Research on Cancer to classify PCE as a probable human carcinogen [4]. As a result, there is a growing consciousness of possible health effects of PCE, and pending restrictions on, PCE use.

The Federal Occupational Safety and Health Administration (OSHA) set the permissible exposure limit (PEL) for PCE in the US at an eight- hour time weighted average (TWA) of 100 parts per million (ppm). The current PEL may not be protective for workers. For example, PCE exposure below the current PEL has been associated with central nervous system (CNS) deficits. Research has established an association with PCE exposure and memory loss [5-7], hearing loss [8], dizziness [6, 8] and visual deficits [9-14]. Furthermore, subclinical CNS toxicity symptoms have been associated with PCE exposure levels of less than 10ppm [10-12, 14].

Some researchers have hypothesized that length of exposure may significantly impact development of CNS toxicity symptoms [5, 6], however evidence is limited. Furthermore, CNS toxicity symptoms associated with solvent exposure may not be transient and there could be long-term sequelae of exposure. Gobba et al. [11] suggested that vision loss did not improve two years after PCE was reduced in the work setting. Likewise, Schreiber et al. [12] found visual contrast sensitivity did not improve six weeks post exposure, indicating a potentially irreversible effect. Finally, one study suggested an association between organic solvent exposure and Parkinson's Disease, [15] indicating organic solvent exposure may have latent health implications.

With the advent of dry-to-dry machines, PCE emissions have drastically decreased [16]. In addition alternatives to PCE are gradually replacing PCE in the dry-cleaning industry[3] . The limited research available on alternative dry-cleaning solvents suggests potential neurotoxic effects associated with exposure [17, 18]. Few studies in the U.S. have examined the prevalence of CNS toxicity symptoms in workers since the introduction dry-to-dry machines and the increased use of alternative dry-cleaning solvents. Organic solvent exposure may still impact the health of the 210,000 dry-cleaning and laundry workers [19] in the U.S. as well as workers in other industries that use organic solvents. Therefore it is important that we understand the risks associated with organic solvent exposure in a more recent dry-cleaner work force.

This study measured the prevalence and risk of four symptoms of CNS toxicity as described by Berde & Strichartz [20]: memory loss, loss of visual perception, dizziness, and tinnitus. The purpose of this study, was to determine the prevalence of self- reported CNS toxicity symptoms and identify predictors that are associated with CNS toxicity symptoms in a sample of 180 dry-cleaner workers who primarily use dry-to-dry machines. We further hypothesized that workers in the high exposure group would be more likely to experience CNS toxicity symptoms compared to their counterparts in the low/ moderate exposure group.

MATERIALS AND METHODS

Study Design and Participants

This cross-sectional study was conducted with a convenience sample of 198 dry-cleaners who were recruited from a pool of 300 members of a U.S. Midwestern state's Korean Dry-cleaners Association and their employees. In addition to the initial contact, one follow-up letter distributed through mailing or visiting ethnic organizations and dry-cleaning shops to increase participation. For the purposes of this analysis, participants who did not provide their job classification or were not employed for at least one year were excluded from this study, resulting in a sample size of 180 dry-cleaners. Data were collected through self-administered surveys. The Institutional Review Board of the University of Michigan approved the study protocol. Individuals who agreed to participate in the study provided written informed consents before completing the study. All participants received $10 gift cards upon completion of the survey.

Measures

The survey questionnaire for the original study was developed through an extensive literature review, focus group discussions, expert review by one NIOSH researcher and two state-employed inspectors, and pilot testing. More detailed information about development and refinement of the survey questionnaire can be found in our earlier publication [(21)]. The current study included questions about demographic information, alcohol consumption, smoking status, work-related characteristics, and knowledge of chemical exposure at work.

Participant Characteristics

Demographics measured included: age, sex, years lived in the U.S., education, ethnicity, self-rated health status, and health insurance status. *Alcohol consumption* was categorized as daily, 2 or 3 times weekly, once a week or less, about 5-6 times a year, and never drank alcohol. *Smoking status* was categorized as “Never smoked”, “Smoked but stopped”, and “Now smoke”. Current smokers were defined as those who responded, “Now smoke”. *Work-related characteristics* included position (owner vs. worker), job classification, and years in the dry-cleaning industry. Worksite characteristics included number of employees, solvent type, and machine type used at each facility.

Solvent Exposure

Exposure to solvents were assessed by participant’s job tasks, which were categorized as dry-cleaner, spotter, presser, counter (cashier), deliverer, sewer or launderer. Based on the reported job tasks, participants were divided into two exposure groups (high versus low or moderate), low and moderately exposed workers were combined because of the small sample sizes (see Table 1). The highest exposure group included dry-cleaner operators and spotters, the moderate exposure group included pressers and launderers, and the low exposure group included cashiers, seamstresses and delivery drivers. This classification of exposure groups was determined using Echeverria et al.’s [6] study that found mean PCE ppm for drycleaners, pressers and cashiers to be 11.4, 4.3 and 0 respectively in closed-loop shops. Gold et al.’s [22] review of PCE levels in dry-cleaning shops between 1990-2002 determined mean dry-to-dry machine operator exposure to be 11ppm.

Most employees reported multiple job tasks. For the purposes of this analysis, each participant was assigned to an exposure group based on the job classification with the highest potential level of exposure to PCE. For example, if a worker marked that he/she has worked as a dry-cleaner operator, cashier and seamstress she was assigned to the high exposure group. An analysis by NIOSH indicated that while TWA PCE air concentration for dry-cleaner operators ranged from 1.6-15.8 for dry-to-dry machines, exposure exceeded 100ppm during and after high exposure activities such as changing machine filters [23].

CNS Toxicity Symptoms

We measured the occurrence of four symptoms of CNS toxicity over a twelve- month period: dizziness, tinnitus, loss of visual perception and memory loss. While Berde and Strichartz [20] include several other symptoms, our analysis was limited to these four because they were the only ones included in the original questionnaire. Frequency of symptoms was measured using a four- point scale categorized as never, sometimes, frequently, and always.

Personal Protective Equipment Use

Personal Protective Equipment (PPE) use was measured using a dichotomous scale for each type of PPE used. Only PPE that minimized solvent exposure was included in the study. Therefore, the analysis was limited to glove, mask/ respirator and apron use.

Personal Protective Behavior (PPB) Engagement

Participation in PPB was determined based on OSHA best practices to reduce exposure. [16] Items included: "Do not overload the machine", "Do not open the machine door when the cycle is running", "Keep the machine door CLOSED as much as possible", "Do not "shortcut" the drying cycle by removing garments from the machine before the cycle is finished", "Keep head and face turned away from the machine door and clothes when removing solvent-laden clothes from the washer", "Do not transfer chemical to machines by hand or with open buckets.", "Wait until the machine and solvent are cold before performing maintenance ", "Use spotting agents sparingly “, “Clean up chemical spills immediately “, “Store containers of chemical and chemical wastes in tightly sealed containers “, “Position head away from the door when opening transfer machines “and “Hold a breath when removing solvent-laden clothes from the washer .“ Responses were dichotomized and summed up to determine the final score.

Data Analysis

All data analysis was completed using the STATA version 12.1 software package (Copyright 1985-2011 StataCorp LP, College Station, Texas). Descriptive statistics (means, standard deviations, frequencies and percentage) were used to describe all study variables. Chi-square analysis for categorical variables and t-test for interval variables were used to examine differences in worker characteristics between the two exposure groups. The effects of the characteristics that were significantly different between exposure groups were further analyzed to determine if they were associated with CNS toxicity symptoms. The Kruskal- Wallis test and ANOVA were used to measure the significance of the effect of key workplace and demographic characteristics on the frequency of CNS toxicity symptoms. Multinomial logistic regression was used to determine prevalence ratio (PR) with 95% confidence intervals (CIs) and p-values for each frequency of memory loss and loss of visual perception. While ordinal logistic regression would have been ideal for our analysis of frequency of symptoms, the data did not meet the assumption of proportional odds, therefore multinomial regression was used [24]. A PR rather than the prevalence odds ratio was selected because the outcome was common with more than 10% of participants reporting memory loss or vision loss. When the outcome of interest is common, use of odds ratios can artificially increase the risk ratio in non case-control studies [25].

RESULTS

Demographic and Work-related Characteristics of the Participants

The data for a total of 180 dry-cleaning workers were included in this analysis. The summary of demographic and work characteristics is presented in Table 1. The majority of participants were Korean (85%), male (60%), and had a post- secondary education (60%). Over 25% were current smokers and a very small percentage (3%) of the respondents reported drinking daily. Most participants (61%) were working owners. Facility characteristics indicated that most facilities continued to use PCE. Of the 102 participants who reported solvent use, 90 (88%) indicated using PCE. Of those who reported machine type, 99 (83%) used chlorinated dry-to-dry machines. Each facility had an average of 5.6 employees.

Differences among exposure groups

Workers in the high- exposure group were significantly older than in the low/ moderate group (50.4 vs. 41 .2 years), worked in the dry-cleaner industry longer (12.1 vs. 9 years); were male (82.0% vs. 27.0%,), were current smokers (33% vs. 15.5%), were owners (81.6% vs. 36.5%), consumed alcohol (61.5% vs. 39.8%) and were more likely to engage in PPB (10.9 vs. 8.6). A detailed description of demographic and work-related characteristics between exposure groups is presented in Table 1.

CNS Toxicity Symptoms

CNS toxicity symptoms were common in this population with 12.8 % reporting tinnitus, 17.8% dizziness, 13.9% memory loss and 23.9% reporting loss of visual perception. Sex, smoking status, age, years in dry-cleaning industry and engagement in PPB were not significantly associated with frequency of CNS toxicity symptoms. Alcohol use and being an owner was associated with tinnitus only. Therefore, these variables were not included in the final multinomial logistic regression analysis. The proportion of participants who reported tinnitus or dizziness did not significantly differ between the two exposure groups. The prevalence of memory loss and loss of visual perception was higher in the high exposure group than in the low/moderate group (see Table 2).

Three variables: owner status, mask use and exposure group were significantly associated with the frequency of memory loss and loss of visual perception (Table 3). However, 81% of owners were in the high exposure group, so owner status was not included in the final model to prevent collinearity. Although glove use was marginally significant (p=0.052), it was controlled for in the final model because PPE use was expected to protect workers from chemical exposure, in turn, reduce likelihood of self-reported CNS symptoms. After controlling for PPE use, workers in the high exposure group were 3.4 times more likely to report loss of visual perception occurring sometimes (PR=3.4; 95% CI: 1.08–10.72) and 4.2 times more likely to report memory loss occurring sometimes (PR=4.2; 95% CI: 0.9-19.6) compared to those in the low/ moderate exposure group (see Table 4).

DISCUSSION

Dizziness prevalence did not differ significantly between exposure groups. Prior studies did find an association between dizziness and PCE exposure [6, 8, 26] however, our results could not replicate those findings. Workers in those studies may have used manual transfer machines therefore were exposed to much higher levels of PCE than our population, which may account for the discrepancy.

Prevalence of tinnitus did not differ significantly between exposure groups, however it differed significantly between both alcohol users and owner status. Previous studies have not measured tinnitus in PCE exposed workers. Only two previous studies to date measured hearing loss in workers exposed to PCE, Cai et al. [8] noted 19.6% of exposed workers versus 1.4% of unexposed workers ($p < .001$) self-reported hearing loss. However, Altmann et al. [9] did not detect significant differences in brainstem auditory evoked potentials among participants exposed to PCE at 50 ppm and 10 ppm in their experimental study.

Loss of visual perception was strongly associated with exposure group. For the high exposure group relative to the low/ moderate exposure group, the relative risk for reporting occasional loss of visual perception increased by a factor of 3.4 controlling for glove and mask use. These results were expected, as previous research has indicated an increased risk of visual disturbances in people exposed to PCE [9-14]. However, our inability to measure type of vision loss (i.e. color vision loss, decreased visual acuity, visual contrast sensitivity), limits our findings.

Prevalence of memory loss was also elevated in the high exposure group, though not significant. For the high exposure group relative to the low/ moderate exposure group, the relative risk for reporting memory loss occurring "sometimes" increased by a factor of 4.2 (95%CI: 0.90-19.64), holding mask use and glove use constant. Previous studies had similar findings, [5-8] although only Echeverria et al.[6] and Altmann et al.[5] used an objective measure to determine memory loss.

The high exposure group had an elevated PR for reporting both memory loss and vision loss occurring "sometimes", but not always or frequently. This may be, in part, due to the low prevalence of memory loss in the higher frequency symptom groups (only 3 respondents in the sample reported memory loss frequently or always). A larger sample size is needed to better understand the association between exposure groups and frequency of symptoms, especially given the wide confidence interval for memory loss.

PPE use did not have a protective effect for workers. This is expected as workers in the high- exposure group were more likely to use PPE than their counterparts in the low/ moderate exposure group (74% of mask/respirator users were in the high exposure group). As this was a cross-sectional study, it was not possible to determine whether workers who reported CNS toxicity symptoms were more likely to use PPE or if PPE did not provide adequate protection. Correct use and type of PPE could not be evaluated. Only 50% of respondents who reported using a mask/respirator reported being fit-tested for a respirator so there is a chance that even those using correct PPE were not using the PPE correctly. A recent study reported that 39% of dry-cleaners in their study used a disposable dust mask and 26% used disposable latex gloves while cleaning machine still bottoms (27). This practice does not comply with OSHA recommendations of use of respirators and chemical resistant gloves during high exposure activities (16). This may explain the lack of protective effect from PPE use as well. Since the primary route of occupational exposure to PCE is through inhalation(1), proper respiratory protection is essential.

Another surprise finding was that being an owner was the strongest predictor of CNS toxicity symptoms in our sample. The majority of owners were in the high exposure group so these groups are strongly correlated. One potential explanation is that owners may work more hours than regular employees and therefore may be exposed to PCE for a longer time period. Future research should account for the number of hours per week worked.

Time in the dry-cleaning industry was not a significant predictor of CNS toxicity symptoms in our sample. While we did expect to find an association, there does not appear to be scientific consensus in regards to the amount of time needed to develop CNS toxicity symptoms. Echeverria et al. (6) estimated that workers had to be exposed for at least three years before symptoms presented. Benignus et al. [28] also hypothesized that chronic exposure might be a better predictor of CNS toxicity symptoms. Given that our cohort primarily used dry-to-dry machines, their exposure levels were much lower than in previous studies.

To date, few studies have measured the effect of PCE exposure on CNS toxicity symptoms in the dry-cleaner setting since the introduction of later generation dry-to-dry machines. Because no recent studies have measured CNS toxicity symptoms as PCE exposure levels have steadily decreased, this study provides novel findings of CNS toxicity in a work-force that primarily use dry-to-dry machines. This study, to the author's knowledge, is also the first to measure prevalence of tinnitus in the dry-cleaner population.

Study limitations should be noted. This cross- sectional study did not evaluate the effect of switching job titles during a worker's tenure or account for exposure history (i.e. switching from transfer to dry-to-dry machines or changing work space). We also did not account for previous neurotoxin exposure or assess for diseases that may also cause CNS toxicity symptoms. Finally, we used subjective, self-reported data. The first two limitations could bias our study toward the null while the last one could bias our study bi-directionally.

We also could not differentiate between part-time and full-time workers. Owners may work the most hours and have the most exposure to PCE. They could also be under the most stress, which has been associated with memory loss [29]. Further research is needed to determine if there is an association between both hours of work and stress with CNS toxicity symptoms in the dry-cleaner population.

Heavy alcohol use can mimic CNS toxicity symptoms and impact performance on some neurobehavioral tests.[6] It is also possible that heavy alcohol use could potentially increase PCE exposure due to poor judgment or coordination while handling PCE. As a whole, the low/

moderate exposure group consumed alcohol less frequently (p=0.01), and all three respondents who reported consuming alcohol on a daily basis were in the high exposure group. However, with the exception of tinnitus, alcohol consumption did not independently impact the likelihood of experiencing CNS toxicity symptoms in our sample.

We were unable to differentiate true exposure levels between the different job titles for multiple reasons. Our reference group is the low- exposure group. However, even the low-exposure group can still be exposed to solvents. Next, most workers have multiple duties and could be exposed in one task but not the others. Workers were assigned to a single job title, regardless of how many tasks they reported. However, a worker may have rarely worked in the high exposure task but still be classified as being in the high exposure group. Finally, exposure group classification is based on data from Echeverria et al.[(6)] study, because we did not have an objective measurement of exposure. Due to high variability in facility workspaces and machine type, we can anticipate variability in exposure as well. Again, if this were to bias our research, it would bias it toward the null.

Because these data are from a convenience sample, generalizabiliy to general population of dry-cleaners is limited, resulting in decreased external validity. First, specific immigrant groups and geographic areas were over-represented. Second, only facilities willing to participate in the study were included. They may have very different characteristics than facilities that did not participate in the study. One threat to internal validity is the healthy worker survivor effect, which posits that workers who are better able to tolerate their work environment are more likely to remain employed in the industry [(30)]. Most of these study limitations bias our results toward the null. Therefore, our significant results are unlikely due to chance. Nevertheless, more research is needed to substantiate these findings.

Implications

Results of this study, if substantiated by future research, indicate several practical considerations for the occupational health professional (OHPs). Although workers in the dry-cleaning industry are exposed to lower levels of dry-cleaning solvents, such as PCE, workers may still experience CNS toxicity symptoms. Therefore OHPs should continue to conduct comprehensive exposure assessments and assess for symptoms of neurotoxicity. Because some CNS toxicity symptoms caused by organic solvents such as PCE may be irreversible, prevention and early diagnosis are key. Therefore, OHPs should include tests sensitive enough to measure subclinical effects indicative of early neurobehavioral deficits. Furthermore, OHPs should provide education regarding protective work practices, and early signs of CNS toxicity. If an OHP suspects that a worker may have CNS toxicity symptoms, consulting with an industrial hygienists and neurologists would ensure comprehensive care for the worker.

While technological advances and use of alternative dry-cleaning solvents have helped to decrease PCE exposure in the dry-cleaning industry, more research is needed to ensure that workers are indeed being adequately protected. The neurotoxic effects of PCE are relatively well established, however, comparatively little is known about the neurotoxic effects of the other dry-cleaning solvents.

CONCLUSION

Our findings indicate that a substantial proportion of dry-cleaner shop employees in our study experienced CNS toxicity symptoms and that workers in the high exposure group were more likely to loss of visual perception compared to their counterparts in the low exposure group. This may indicate that workers have been exposed to organic solvent levels that exceed current PELs, that current PELs for organic solvents used in dry-cleaning are not protective enough, that these effects are residual effects from prior exposure to PCE at much higher levels or that there is another environmental factor impacting CNS toxicity in this population. Given the high prevalence of CNS toxicity symptoms, further research is warranted to explore this association. Future studies should account for number of hours worked per task, past solvent exposure levels, control for factors that may cause CNS toxicity symptoms such as alcohol use and stress as well as use validated, objective measures of both exposures and CNS toxicity symptoms.

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Table I. Characteristics of Study Participants (N=180).

Characteristics	**Total**	**Low Exposure**	**High Exposure**	
	n (%)	**n (%)**	**n (%)**	**p-value**
Demographic Characteristics				
Education (n=171)				0.166
Less than high school	7 (4.1)	3 (4.2)	4 (4.0)	
High school	61 (35.7)	33 (35.7)	28 (28.0)	
Associate degree or trade school	26 (15.2)	9 (12.7)	17 (17.0)	
Bachelor	72 (42.1)	24 (33.8)	48 (48.0)	
Graduate degree	5 (2.9)	2 (2.8)	3 (3.0)	
Gender (n=179)				**<.001**
Male	106 (59.7)	20 (27.0)	86 (81.9)	
Female	73 (40.8)	54 (73.0)	19 (18.1)	
Ethnicity (n=186)				**<.001**
Korean	153 (85.0)	51 (68.9)	102 (96.2)	
African-American	19 (10.6)	16 (21.6)	3 (2.8)	
White	4 (2.2)	4 (5.4)	0	
Latino	4 (2.2)	3 (4.0)	1 (0.9)	
Alcohol use (n=164)				**.043**
Daily	3 (1.8)	0 (0)	3 (3.1)	
2 or 3 times weekly	14 (8.5)	4 (5.9)	10 (10.4)	
Once a week or less	37 (22.6)	12 (17.6)	25 (26.0)	

About 5-6times a year	31 (18.9)	10 (14.7)	21 (21.9)	
Never drank alcohol	79 (48.2)	42 (61.8)	37 (38.5)	
Smoking status (n=168)				**.010**
Current smokers	43 (25.6)	11 (15.5)	32 (33.0)	
Non-smokers	125 (74.4)	60 (84.5)	65 (67.0)	
Age (Years) Mean, (SD) (16-71)	46.5 (11.7)	41.2 (12.1)	50.4 (9.6)	**<0.001**
Occupation- related characteristics				
Years in dry-cleaning industry Mean, (SD), range (1.0-30)	10.8 (7.4)	9 (7.5)	12.1 (7.0)	**0.005**
Personal protective behavior score, Mean (SD), range 0-12	10.18 (3.35)	8.62 (4.7)	10.94 (2.1)	**<0.001**
Personal protective equipment use(n=145)				
Gloves	80 (55.2)	22 (42.3)	58 (62.4)	**0.020**
Mask/ respirator	50 (36.0)	13 (25.0)	37 (42.5)	**0.037**
Protective clothing/ apron	19 (14.3)	7 (14.3)	12 (14.3)	1.0
Position (n=172)				**<.001**
Owner and worker	107 (62.2)	27 (36.5)	80 (81.6)	
Worker only	65 (37.8)	47 (63.5)	18 (18.4)	
Duty [#] (n=180)				-
Drycleaner	100 (55.5)	-	-	
Spotter	94 (52.2)	-	-	
Presser	85 (47.2)	-	-	
Counter (Cashier)	130 (72.2)	-	-	

Deliverer	25 (14.0)	-	-
Sewer	59 (32.8)	-	-
Laundry	52 (33.0)	-	-
Other	16 (8.9)	-	-

Facility characteristics	**n (%)**
Number of employees, Mean (SD); range 1- 24	5.6 (3.4)
Type of machine used (n=119)	
Chlorinated dry-to-dry	99 (83.2)
Non-chlorinated dry-to-dry	13 (10.9)
Chlorinated transfer cleaner	7 (5.9)
Type of solvent used (n=102)	
Use PCE	90 (88.4)
Use PCE alternative	12 (11.6)

Multiple responses (participants select all that apply)

Table II. Prevalence of central nervous system toxicity symptoms (N=180).

Symptoms	Total	Low Exposure	High Exposure	p-value
	n (%)	n (%)	n (%)	
Tinnitus (total)	23 (12.8)	8 (10.2)	15 (14.2)	0.494
Sometimes	19 (10.6)	7 (9.5)	12 (11.3)	
Frequently	3 (1.7)	1 (1.3)	2 (1.9)	
Always	1 (0.6)	0	1 (0.9)	
Dizziness (total)	32 (17.8)	12 (16.2)	20 (18.9)	0.611
Sometimes	30 (16.7)	12 (16.2)	18 (17)	
Frequently	1 (0.6)	0 (0)	1 (0.9)	
Always	1 (0.6)	0 (0)	1 (0.9)	
Memory Loss (total)	25 (13.9)	5 (6.8)	20 (19.9)	**0.026**
Sometimes	22 (12.2)	3 (4.0)	19 (17.9)	
Frequently	2 (1.1)	2 (2.7)	0 (0.0)	
Always	1 (0.6)	0 (0.0)	2 (0.9)	
Loss of Visual Perception (total)	43 (23.9)	11 (14.9)	32 (30.2)	**0.032**
Sometimes	32 (17.8)	6 (8.1)	26 (24.5)	
Frequently	7 (3.9)	2 (2.8)	5 (4.7)	
Always	4 (2.2)	3 (4.0)	1 (0.9)	

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Table III. Predictors of CNS Toxicity Symptoms.

Variables	Tinnitus	p-value	Dizziness	p-value	Memory loss	p-value	Vision loss	p-value
	Mean(SD)		Mean(SD)		Mean (SD)		Mean(SD)	
Age	50.1 (6.8)	0.467	46.2 (11.1)	0.721	49.7 (6.9)	0.377	49.6 (7.8)	0.278
Time in industry	9.0 (4.7)	0.637	9.7 (5.4)	0.911	9.9 (4.4)	0.750	9.9 (6.4)	0.734
PPB	10.1 (2.9)	0.981	10.0 (2.9)	0.911	10.6 (1.7)	0.900	10.7 (1.6)	0.679
	n (%)	**p-value**	**n (%)**	**p-value**	**n (%)**	**p-value**	**n (%)**	**p-value**
Gender		0.835		0.638		0.967		0.717
Male	14 (13.2)		20 (18.9)		15 (14.1)		27 (25.4)	
Female	9 (12.3)		12 (16.4)		10 (13.7)		16 (21.9)	
Owner Status		**0.039**		0.121		**0.020**		**0.006**
Owner+ worker	18 (16.8)		23 (21.5)		20 (18.7)		32 (29.9)	
Worker	4 (6.15)		8 (12.3)		4 (6.1)		7 (10,8)	
		0.036		0.908		0.555		0.695

Alcohol use								
Daily	0 (0.0)		0 (0.0)		1 (33.3)		0 (0.0)	
2-3times/week	3 (21.4)		3 (21.4)		3 (21.4)		5 (35.7)	
< 1time/week	4 (10.8)		6 (16.2)		5 (13.5)		10 (27)	
5-6times/year	9 (29.0)		5 (16.1)		6 (19.3)		8 (25.8)	
Never drink	6 (7.6)		15 (19.0)		8 (10.1)		16 (20.2)	
Smoking status		0.441		0.988		0.697		0.083
Current smokers	7 (16.3)		8 (18.6)		7 (16.3)		15 (34.9)	
Non-smokers	15 (12.0)		23 (18.4)		17 (13.6)		26 (20.8)	
Exposure Group		0.495		0.611		**0.026**		**0.032**
High	15(14.1)		20 (18.9)		20 (18.9)		32 (30.2)	
Low/ moderate	8(10.8)		12 (16.2)		5 (6.8)		11 (14.9)	
PPE use (yes)								
Glove use	12 (15.0)	0.486	18 (22.5)	0.292	14 (17.5)	0.160	25 (31.2)	**0.052**
Mask use	9 (18)	0.486	12 (24)	0.264	11 (22)	**0.040**	15 (30)	0.355

Table IV. Risk of Memory Loss and Loss of Visual Perception (by Frequency of Occurrence) in the High Exposure Group Controlling for Mask and Glove Use.

Frequency of symptoms	CNS Depression Symptoms in High Exposure Group**			
	Memory Loss		Loss of Visual Perception	
	PR (95% CI)	***P*-value**	**PR (95% CI)**	***P*-value**
Always	-		0.3 (0.02-3.6)	0.346
Frequently	-	-	0.96 (0.150-6.17)	0.967
Sometimes	4.2 (0.90-19.64)	0.067	**3.4 (1.08-10.73)**	**0.037**

PR= prevalence ratio

**moderate/low group is reference group

Chapter 4

Factors Associated with Safe Work Behavior in Dry-Cleaners: Application of the Health Belief Model

Chapter 4

Factors Associated with Safe Work Behavior in Dry-Cleaners: Application of the Health Belief Model

Abstract

Background: The injury incidence rate due to exposure to hazardous substances and environments is 3.1 times higher in the dry-cleaning industry versus the rest of the private sector. Even so, many workers in the dry-cleaning industry are not engaging in safe work behavior (SWB).

Purpose: To determine predictors and barriers of SWB in dry-cleaners and to determine if perceived threat predicts SWB.

Methods: We used the Health Belief Model to identify the predictors of SWB in a cross-sectional study of 169 dry-cleaner facility workers. We used multiple linear regression to determine predictors of SWB, specifically personal protective behavior (PPB) and personal protective equipment (PPE) use.

Results: Receiving safety training and working in high exposure group predicted PPB with the final model explaining 30% ($p<0.001$) of variance in PPB. Being an owner, a male, having a lower perceived exposure score, and perchloroethylene use predicted PPE use, explaining 32% ($p<0.001$) of variance in PPE use. Discomfort was the primary barrier to PPE use.

Discussion: Interventions should focus on increasing worker training and PPE use, especially at dry-cleaning facilities that use perchloroethylene.

Keywords: health belief model, safe work behavior, occupational exposure

Background

Over 210,000 workers employed in the dry-cleaning/ laundry industry in the United States (U.S.) (National Institute for Occupational Safety and Health [NIOSH], 2002) work in an inherently risky environment. One national survey of a random sample of dry-cleaner workers found sixty percent of respondents report being exposed to contaminants on a daily basis (National Center for O*NET Development, 2010). In 2013 the illness and injury rate requiring time away from work due to "exposure to harmful substances or environments" was 13.7 per 10,000 full-time dry-cleaner workers compared to 4.4 in all other workers in the private sector(U.S. Bureau of Labor Statistics, 2015). This is likely an underestimation of the burden of illnesses and injuries within the dry-cleaning industry because this only accounts for time away from work. Illnesses may be subtle or latent (Committee of Education and Labor, 2008; Wiatrowski, 2014) and underreporting is substantially increased in small industries (Morse et al., 2004). Organic solvents (substances that can dissolve other substances) are a source of illness and injury in the cleaning workforce. Workers in the dry-cleaning industry are primarily exposed to one organic solvent, Perchloroethylene (NIOSH, 2012).

Exposure to perchloroethylene can occur through inhalation, ingestion and dermal contact. Approximately 75% of inhaled Perchloroethylene is absorbed by the lungs and 80% of ingested Perchloroethylene is absorbed by the gut (Agency for Toxic Substances and Disease Registry[ATSDR], 2007). The estimated half-life of Perchloroethylene in adipose tissue is 55 hours and 12-16 hours in highly vascularized tissues (ATSDR, 2007). This, combined, with the relatively slow excretion of perchloroethylene suggests that chronic, low-level exposure of Perchloroethylene may have potentially deleterious effects.

Based on substantial evidence of the carcinogenicity, Perchloroethylene was classified as a probable human carcinogen (2A) in 1997 (International Agency for Research on Cancer, 1997). Perchloroethylene exposure below the permissible exposure limit has also been associated with neurotoxicity (Altmann, Neuhann, Kramer, Witten, & Jermann, 1995; Altmann, Wiegand, Bottger, Elstermeier, & Winneke, 1992; Cai et al., 1991; Cavalleri et al., 1994; Echeverria, White, & Sampaio, 1995; Ferroni et al., 1992; Getz et al., 2012; Gobba et al., 1998; Janulewicz et al., 2012; Stewart, Baretta, Dodd, & Torkelson, 1970; Storm et al., 2011).

In order to reduce workers' exposure to occupational hazards, NIOSH recommends a hierarchy of controls focusing on: elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE) (NIOSH, 2010). Within the dry-cleaning industry, switching solvents can be costly (Hesari, Francis, & Halden, 2014), but the use of engineering controls such as dry-to-dry machines and condensers is now mandated (Environmental Protection Agency [EPA], 1993). Due to advances in technology, Perchloroethylene emissions have substantially decreased. However, workers can still be exposed to high levels of Perchloroethylene during routine maintenance of machinery, loading and unloading clothes, opening machine door mid- cycle, and through fugitive emissions that can occur as a result of a leak (Occupational Safety and Health Administration [OSHA], 2005).

It is essential to ensure that workers are engaging in safe work behavior (SWB), which is comprised of personal protective behavior (PPB) and use of personal protective equipment (PPE) to reduce solvent exposure. Studies document the lack of engagement in SWB (Cox et al., 2003; Goldenhar et al., 1999; Whittaker & Johanson, 2013). Two qualitative studies noted that workers who were not concerned about Perchloroethylene exposure did not use PPE and believed that their dry-cleaning machines provided adequate protection (Cox et al., 2003;

Goldenhar et al., 1999). While workers were concerned about Perchloroethylene exposure, they could not state health effects associated with exposure (Goldenhar et al., 1999).

Several factors may hinder a worker's ability to fully understand how to engage in SWB, including job training and education level. Approximately 40% workers in this industry do not have a high school diploma (National Center for O*NET Development, 2010). One study of 49 janitors found language barriers, lack of training and minimal supervisor support contributed to health outcomes associated with chemical exposure (Pechter, Azaroff, Lopez, & Goldstein-Gelb, 2009). A cross-sectional study of 475 drycleaners in Washington revealed that 84% of workers prefer to receive information in a language other than English (Whittaker & Johanson, 2013).

Business size may also impact SWB. The dry-cleaning industry consists of mainly small facility with less than 10 employees (NIOSH, 2012). Given the lack of resources, small businesses may have limited capacity to address occupational health and safety or know of regulations (NIOSH, 2002). In one study of small businesses in the automotive collision repair industry, neither workers or owners were aware of chemical "right-to-know training" and respiratory equipment fit-testing (Parker, Bejan, & Brosseau, 2012). Thus, there needs to be a better understanding of factors that promote SWB in order to develop interventions that can further decrease worker exposure to harmful chemicals.

The purpose of this research is to identify factors that promote SWB in English and Korean speaking dry-cleaners in the Midwest. A further understanding of factors that promote SWB may help to develop interventions to improve compliance with OSHA recommended practices thus decreasing chemical exposure. This will not only benefit workers, but, when workers engage in PPB, it can potentially decrease exposure to their immediate community. The hypothesis for this study is that perceived threat predicts engagement in SWB.

Conceptual Framework

A conceptual model (Figure 2) based on the health belief model (HBM) guided this research. The HBM hypothesizes that people will engage in safe behavior if they regard themselves as susceptible to a severe consequence of a given threat and that engaging in the behavior will decrease the risk (Rosenstock, 1966). Additionally, benefits must outweigh the barriers to engaging in the behavior and that a prompt (*cue to action*) is needed to trigger the behavior (Rosenstock, 1966). Finally, demographic factors can influence the effects of perceived threat and SWB.

In our modified model, the outcome of interest is SWB, which is operationalized by engagement in PPB or using PPE. The predictor of interest, perceived threat is operationalized by two measures: perceived exposure (PE) and perceived susceptibility (PS). The model also assumes that demographic characteristics and cues to action can predict SWB.

Methods

Participants/ Data Collection

This cross-sectional study uses secondary data from a study conducted with a convenience sample of 198 dry-cleaner facility employees who were recruited from a pool of 300 members of a U.S. Midwestern state's Korean Drycleaners Association and their employees. Inclusion criteria included employment in dry-cleaning facility and ability to read English or Korean. For the purposes of this analysis, participants who did not complete at least 33% of the questionnaire items of interest (n=23) or did not work in dry- cleaning for at least one year (n=6) were removed from the analyses, resulting in a final sample size of 169 participants.

The questionnaire was developed based on extensive literature review, focus groups, and consultation with a state inspector and was pilot tested before it was distributed. Participants provided informed consent before completing the survey. Data were collected through self-administered surveys and one follow-up letter distributed through mailing or visiting ethnic organizations and dry-cleaning facilities. More information on the study protocol and survey instrument development can be found elsewhere (Chin, Duffy, & Hong, 2014).

The Institutional Review Boards of the University of Michigan and University of California, San Francisco approved the original study protocol and the secondary analysis, respectively.

Measures

Outcome Variables. The outcome SWB, is operationalized by two variables:

Personal protective equipment Use- Three types of PPE were measured: use of mask/respirator, gloves and apron/protective clothing. Responses were dichotomized (yes/no) and summed up to determine the final score, which ranged from 0-3.

Personal protective behavior engagement- The PPB scale was based on OSHA best practices to reduce exposure. See Table 2 for the list of practices. A total of 12 items with a dichotomized (yes/no) response, and summed up to determine the final score, which ranged from 0-12.

Predictor Variables. The predictor, perceived threat, is operationalized by the following:

Perceived Exposure. This 12- item scale (Cronbach's alpha 0.89) measured perception of exposure sources during the dry-cleaning process. A full description of this questionnaire is found elsewhere (Chin, Duffy, & Hong, 2014). Each item was scored 1-6, with a higher score indicating a higher level of agreement with the statement. The final mean score could range from 1-6.

Perceived Susceptibility. This 10- item scale (Cronbach's alpha 0.96) measured the strength of belief that exposure to chemicals may cause the following health effects: sore eyes, skin irritation, dermatitis, headaches, dizziness, memory loss, liver damage, kidney damage, or nervous system damage. Each item was scored 1-6, with a higher score indicating a higher level of agreement with the statement. The final mean score could range from 1-6.

Barriers to PPE use. Participants who did not use PPE were asked to select one of the following reasons as to why they did not use each type of PPE: not helpful, uncomfortable, no one uses in my shop, cost, or ugly.

Covariates.

Demographics. Personal characteristics measured included: age (continuous), sex (male/ female), years lived in the US (continuous), years working in the dry-cleaning industry (continuous), education level (categorical), smoking status (yes/no), drinking status (yes/no).

Work-related characteristics. These included: perchloroethylene use (yes/no), number of machines on site (greater or less than two), number of employees (continuous), owner status (owner vs. worker) and exposure group classification based on job title (dry-cleaner operators and spotters in the high exposure group; all other job titles in the low/ moderate exposure group).

Cues to action. Two types of cues to action (internal and external) are used. The internal cue to action was estimated based on mean *exposure symptoms*, which is the mean frequency of the following symptoms in the past year: eye irritation, nose irritation, throat irritation, skin irritation, headache, dizziness, nausea, memory loss, loss of visual perception, hearing loss and tinnitus. Scores range from 1-4 (1 is never experiencing any symptoms; 4 is always experiencing all symptoms). The external cue to action *training (score)* was estimated based on participants' (yes/ no) responses to receiving training within the past year on the following five topics: proper work practices; health hazards and symptoms associated with chemical exposure; proper use of PPE; procedures for responding to emergencies, such as splashes and skin contamination, and an open-ended other response. The final score could range from 0-5. The second external cue to action, *frequency of inspection*, was based on the reported number of inspections per year.

Analysis

Data analysis was conducted using the STATA version 12.1 (Copyright 1985-2011 StataCorp LP, College Station, Texas). Descriptive statistics (means, standard deviations, frequencies and percentage) were calculated to describe all study variables. Cronbach alpha was calculated to determine if the subscales were reliable. Multiple linear regression was used to determine if there is an association between perceived threat and engagement in SWB after controlling for covariates. In an effort to create a parsimonious model, backwards-stepwise regression was used to remove covariates. Once all covariates remaining in the model had a p-value < 0.25 (Hosmer & Lemeshow, 2000), the primary predictors of PES and PS were added to the model. Backwards-stepwise regression was used again until the remaining variables all had a p-value < 0.25. Model fit was determined based on a decreased Bayesian information criteria (BIC) statistic and an increase in percent of variance explained.

Several variables had missing values (Table 1). Therefore, maximum likelihood for missing values was used to estimate values for the missing variables. This is a preferable method to list-wise deletion (Enders, 2010) or multiple imputation when the outcome variable is missing (Vittinghoff, 2012). Bootstrap estimation (using 2000 re-sampled datasets, with replacement) was used to correct for the non-normal distribution of the data and provides a better estimate of distortions due to small sample sizes that do not reflect population values. Since bootstrap estimation alters the standard error (Enders, 2010), significance is determined based on a bias corrected confidence interval.

Results

Characteristics of Study Participants

Participants were Korean-Americans (86.4%), males (63.7%), facility owners (67%), in the high exposure group (67%), had a bachelor's degree (42%), non-smokers (75.2%) and non-drinkers (47.5%). Most facilities had less than two machines (63.2%) and used Perchloroethylene (82%). Mean PPB score was high (10.3) and PPE use was low (0.97). Nearly 70% of participants reported had not received training within past year (Table 1).

Predictors of PPB

The covariate model included number of machines on site, training, owner status and exposure group. All predictors in the covariate model in addition to PES and PS were predictors of PPB in the final model; however only training and exposure group was significant in the final model (Table 3). Being in the high exposure group and having a higher PS score and receiving training were positively associated with PPB. The BIC increased from 1873 in the covariate model to 2851 in the final model, indicating poorer model fit in the final model. However, the final model explains 30% of variance in PPB compared to only 26% of variance in the covariate model.

Predictors of PPE

The covariate model included the following predictors of PPE use: sex, training, owner status, mean symptom score, alcohol consumption and exposure group and perchloroethylene use. In contrast only owner status, perchloroethylene use, sex, training and mean symptom score were predictors in the final PPE model (Table 4), of which only PES, perchloroethylene use, being female and being an owner were statistically significant. Only experiencing symptoms and being an owner of a dry-cleaning facility were positively associated with PPE use. The BIC decreased from 2551 in the baseline model to 2260 in the final model, indicating improved model fit. The final model explained 32% of variance in PPE use compared to 31% in the covariate model.

Barriers to use of PPE

Among participants who reported not using PPE, the primary reason was discomfort associated with use (Table 4). This is similar to other studies reporting that PPE was cumbersome (Cox et al., 2003; Pechter et al., 2009). Other reasons include believing that PPE is not helpful and that co-workers do not use PPE. Among participants who stated they did not use PPE because their co-workers did not, it is unclear whether PPE was not available or, if available, the work culture did not promote use.

Discussion

This study found that the components of perceived threat were not associated with increased PPE use and engagement PPB. PES was negatively correlated with both PPE use and PPB. In regards to PS, there was a positive, though not significant, association between PS and PPB, which is similar to other studies (Arcury, Quandt, & Russell, 2002; Martinez, Gratton, Coggin, Rene, & Waller, 2004). Two cues to action, presence of symptoms (internal) and training (external) and were associated with PPE use. It was of interest to note that training was positively associated with PPB while PES was negatively associated since training would presumably increase knowledge of exposure sources. Receiving training may be indicative of a stronger safety culture at the work-site or receiving training may increase self-efficacy. Approximately 69% of participants had not received any training in the past year, thus pointing to the importance of ongoing training in the dry-cleaning industry.

Personal characteristics were stronger predictors of PPE use than for PPB. Being female was associated with decreased use of PPE while experiencing symptoms was associated with increased use of PPE. Being an owner of a dry-cleaning facility was the only predictor associated with increased PPE use and PPB. Although this may seem intuitive, since owners were more likely to be in the high exposure group and have more control in engaging in SWB, these findings contradict Goldenhar et al.'s (1999) findings, where owners were hesitant to use PPE.

PPB scores are high but PPE use is low (Table 2). This may be because of the stringent EPA regulation that requires dry-cleaner facilities to follow regulations that dictate PPB in order to reduce community exposure (EPA, 2008). Conversely, PPE use is not enforced, but strongly recommended by OSHA. If PPB practices are followed, workers may feel that their exposure to solvents is sufficiently reduced, and therefore PPE use is no longer necessary. In addition discomfort is associated with PPE use, where as engagement in PPB is not associated with discomfort.

We found that employees who use perchloroethylene were less likely to use PPE compared to their counterparts who use other solvents. This is of interest because perchloroethylene alternatives are presumed to be safer than perchloroethylene.

A strength of this study is the inclusion of immigrant populations, who, due to language difficulties, would be excluded from other research. This is of particular importance in that immigrant workers make up a substantial portion of the dry-cleaning industry (Bureau of Labor Statistics, 2014) and may have unique situations such as language barriers or cultural norms that contribute to exposures and symptoms. Also, while objective measures such as work-site audits and workers compensation claims are preferable, use of self-report data may be the only option for a study with workers in family-based small industries that are not required to report any injuries.

A limitation of the study is the study design, which decreases our ability to generalize the findings to the general population of drycleaners in the U.S., resulting in decreased external validity. Specific racial groups and geographic areas were over-represented. Second, a convenience sample of facilities was included; these facilities may be different from other facilities that did not participate in the study.

The only engineering control assessed in the study was machine type (transfer vs. dry-to-dry machine). Among participants who reported machine-type, all had at least one dry-to-dry machine on site however exposure can still vary based on the type of dry-to-dry machine, use of ventilation devices and refrigerated condensers. These factors may also impact whether a worker feels it is necessary to engage in SWB. Therefore, it would have been beneficial to assess these engineering controls. We also did not assess whether PPE was used correctly. In this study, 44% of participants who indicated using respiratory protection had been fit-tested for a respirator mask. One study reported that 39% of dry-cleaners in their sample used a dust mask and 26% used latex gloves while cleaning machines, thus this is an important factor to assess (Whittaker & Johanson, 2013). There was also no measure of frequency of engaging in SWB. For example, using PPE is especially important during maintenance tasks, so it is important to know when PPE is being used.

Self-efficacy, a strong predictor of SWB (Arcury et al., 2002; Ben-Ami, Shaham, Rabin, Melzer, & Ribak, 2001; Glanz, Rimer, & Lewis, 2002; Martinez et al., 2004) and perceived benefits, are important elements of the HBM, but could not be included in secondary analysis.

Measuring health beliefs and behaviors at the same time can also result in a spurious association between the variables (Glanz et al., 2002).

Based on these study limitations, future research should account for use of engineering controls, frequency and correct use of PPE in order to more accurately measure SWB. Future studies should account for self-efficacy and safety culture as these may be predictors of SWB. The findings of this current study should be further explored through longitudinal studies that have sufficient sample size to control for potential confounders.

Conclusion

To the author's knowledge, this study is the first study to apply the HBM to determine predictors of SWB in dry-cleaning workers exposed to solvents. Previous occupational chemical exposure studies that used the HBM have focused on cytotoxic drug handling practices among nurses (Ben-Ami et al., 2001) and PPB of workers using pesticides (Arcury et al., 2002; Martinez et al., 2004). Two qualitative studies examined reasons for SWB in dry-cleaners (Cox et al., 2003; Goldenhar et al., 1999), however this is the first study to measure strength of association between predictors and SWB.

Based on results of this study, the components of perception of threat were not associated with an increased use of PPE. Only PS had a weak, non-significant positive association with PPB. The only modifiable predictor of SWB was training, indicating that future interventions should focus on improving the frequency and quality of training in order to reduce solvent exposures and thus prevent negative health outcomes among dry-cleaning workers.

Interventions identified in this study include ensuring that workers receive frequent training from approved agencies. PPE use and worker training should be part of the standard inspection checklist that drycleaners are required to complete. More emphasis on the health effects of solvent exposure may further increase compliance with OSHA best practices. PPE use is still low among workers; therefore training should focus on when and how to properly use PPE. Further interventions should also focus on decreasing discomfort associated with PPE use.

Occupational exposure to solvents can increase risk of illnesses and injuries among workers in the dry-cleaner industry. Because some effects may be irreversible, primary prevention is needed to ensure workers are protected. While perchloroethylene is being phased out in some settings (EPA, 2008), it is being replaced with other solvents that may have deleterious health effects. Removing solvents from the work environment is ideal; if removal cannot be assured, then minimizing exposure becomes crucial.

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Table 1

Characteristics of the Study Participants

Personal Characteristics	Mean (SD); Range
Age, years (n=156)	46.7 (12.2); (16-71)
Years in the United States (n=160)	19.6 (10.4); (2-56)
Years in industry (n=161)	11.1 (7.5); (1-30)
Mean Symptom Score (n=152)	1.47 (.64); (1-4)
Training sessions in last 12 months (n=160)	.65 (1.2); (0-5)
Education (n=161)	**Percent (n)**
Less than high school	3.7 (6)
High school	36 (58)
Associate degree or trade school	14.9 (24)
Bachelor	42.2 (68)
Graduate degree	3.1 (5)
Sex (n=168)	
Male	63.7 (107)
Female	36.3 (61)
Owner Status (n=159)	
Owner and Worker	66.7 (106)
Worker	33.3 (53)
Exposure Group (n=165)	
High	61.8 (102)
Low/ Moderate	38.2 (63)
Smoking Status (n=157)	
Current Smoker	24.8 (39)
Non-Smoker	75.2 (118)
Alcohol use (n=158)	
Daily	2.5 (4)
2 or 3 times weekly	10.1 (16)
Once a week or less	22.1 (35)
About 5-6times a year	17.7 (28)
Never drank alcohol	47.5 (75)
Ethnicity (n=169)	
Korean	86.4 (146)
Black	10.1 (17)
Hispanic	2.4 (4)
White	1.2 (2)

Worksite Characteristics	Mean (SD); Range
Inspections in past 12 months (n=133)	1.85 (1.8); (0-10)
Number of employees (n=120)	5.7 (3.4); (1-24)
Number of machines (n=106)	**Percent (n)**
Less than two	63.2 (67)
Two or more	36.8 (39)
Solvent Use (n=110)	
Perchloroethylene (PCE)	81.8 (90)
Other	18 .2 (20)
Predictors of Interest	**Mean (SD); Range**
Perceived Susceptibility Score (n=155)	3.9 (1.4); (1-6)
Perceived Exposure Source Score (n=133)	3.6 (1.1); (1-6)
Outcome Variables	**Mean (SD); Range**
Personal Protective Behavior Score (n=140)	10.3 (3.3); (0-12)
Personal Protective Equipment Score (n=134)	0.97 (1.0); (0-3)

Note: N=169

Table 2

Prevalence of Safe Work Behavior (SWB) as measured by Personal Protective Behaviors and Personal Protective Equipment Use

Personal Protective Behaviors	**% (n)**
Do not "shortcut" the drying cycle by removing garments from the machine before the cycle is finished	91.8 (134)
Hold a breath when removing solvent-laden clothes from the washer	91.4 (127)
Keep the machine door CLOSED as much as possible	91.0 (132)
Keep head and face turned away from the machine door and clothes when removing solvent-laden clothes from the washer	89.6 (129)
Clean up chemical spills immediately	89.4 (127)
Store containers of chemical and chemical wastes in tightly sealed containers	87.6 (127)
Position head away from the door when opening transfer machines	87.4 (125)
Do not open the machine door when the cycle is running	87.0 (127)
Do not overload the machine	83.9 (120)
Do not transfer chemical to machines by hand or with open buckets.	80.6 (116)
Use spotting agents sparingly	80.1 (113)
Wait until the machine and solvent are cold before performing maintenance	79.6 (113)
Personal Protective Equipment Use	**% (n)**
Glove use	55.6 (84)
Mask/ Respirator use	37.8 (54)
Apron/ Protective clothing use	14.4 (20)

Table 3.
Predictors of Personal Protective Behavior

	Covariate Model		Final Model	
Variable	*B*	95% CI	*B*	95% CI
Perceived exposure (sources)	-	-	-0.56	-1.16, 0.01
Perceived susceptibility	-	-	0.35	-0.09, 0.77
Number of machines	-1.9	**-3.65, -0.15***	-1.82	-3.2, 0.52
Training	0.48	**0.02, 0.94***	0.53	**0.1, 1.04***
Owner	1.19	-0.39, 2.78	1.62	-0.01, 3.32
High exposure group	1.45	**0.3, 2.6***	1.31	**0.35, 2.61***
R^2	0.26**		0.30**	
BIC	1873		2851	
ΔR^2			0.04	
ΔBIC			978	

Note: N=169. CI= Confidence Interval, B= coefficient *= significant 95% confidence interval**= p<.01

Table 4
Predictors of Personal Protective Equipment Use

	Covariate Model		Final Model	
Variable	*B*	95% CI	*B*	95% CI
Perceived Exposure Sources	-		-0.17	**-0.32, -.02***
Perchloroethylene use	-0.89	**-1.36, -0.41***	-0.78	**-1.27, -0.2***
Female	-0.64	**-1.05, -0.23***	-0.52	**-0.85, -0.19***
Training	-0.14	**-0.26, -0.02***	-0.13	-0.25, 0.003
Owner	0.55	**0.12, 0.98***	0.596	**0.22, 0.98***
Mean Symptom score	0.25	-0.11, 0.62	0.296	-0.02, 0.69
Alcohol Consumption	-0.09	-0.23, 0.04	-	
High Exposure Group	-0.28	-0.69, 0.13	-	
R^2	0.31**		0.32**	
BIC	2551		2260	
ΔR^2			0.1	
ΔBIC			-291	

Note: N=169. CI= Confidence Interval, B= coefficient, *= significant 95% confidence interval, **= p<.01

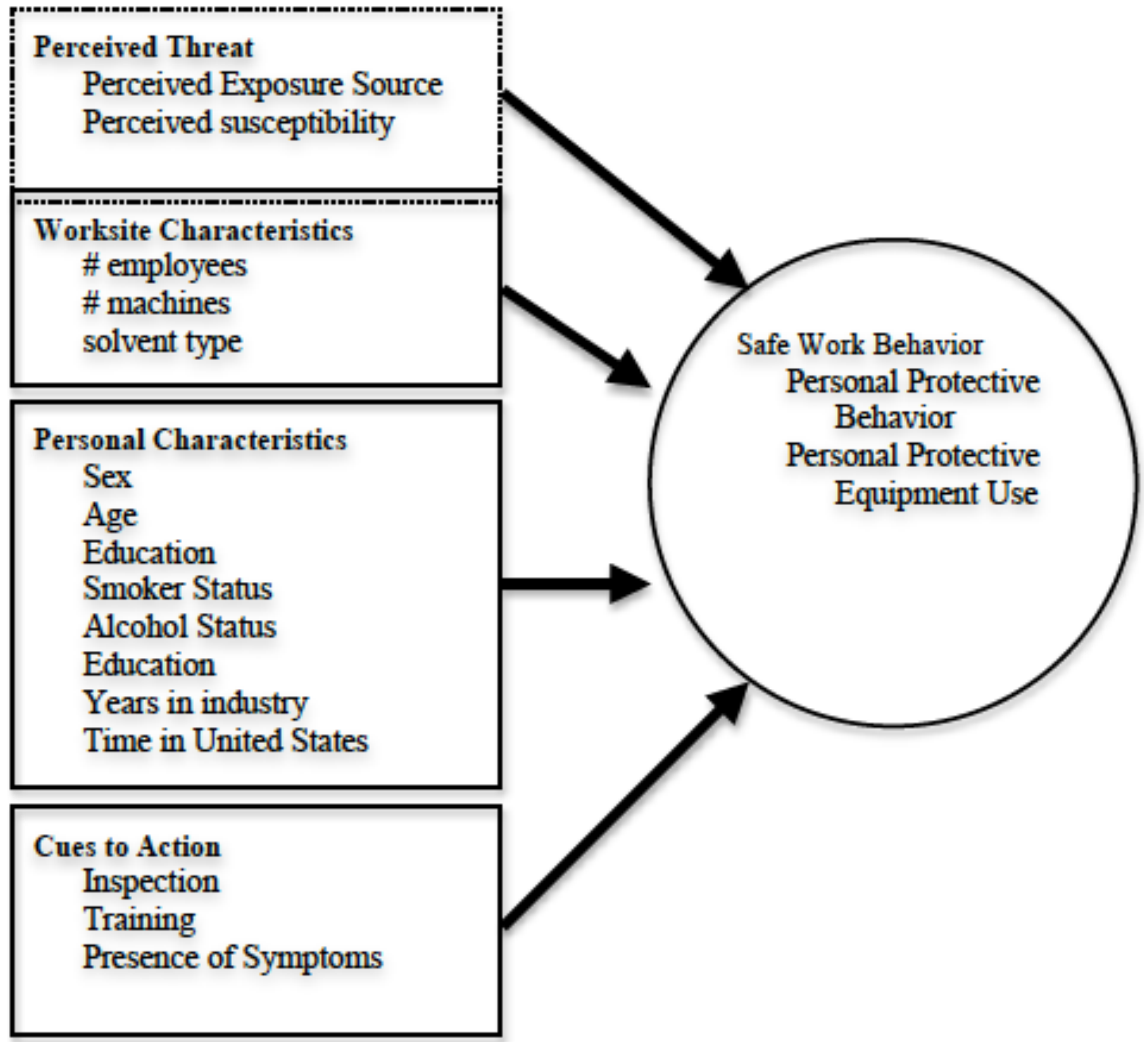
Table 5

Barriers to Personal Protective Equipment Use

	Discomfort % (n)		Not helpful % (n)		No one uses % (n)	
PPE Type	High	Low	High	Low	High	Low
Gloves (n=89)	45(80.4)	17 (53.1)	6 (10.7)	5 (15.6)	4 (7.1)	9 (28.1)
Mask (n=105)	49 (75.4)	19 (48.7)	8 (12.3)	6 (15.4)	7 (10.8)	13 (33.3)
Apron (n=126)	43 (53.7)	19 (44.2)	24 (30)	10 (23.3)	11 (13.7)	11 (22.6)

Figure 2

Conceptual Model of Predictors of Safe Work Behavior Adapted From Health Belief Model



Chapter 5

Summary and Conclusion

Chapter 5

Summary

The overall purpose of this dissertation is to evaluate the actual and perceived risk of solvent exposure and prevalence of SWB in the dry-cleaner workforce. While solvent exposure has been linked to several health outcomes, this dissertation focused specifically on neurotoxic effects of solvents as measured by symptoms of CNS toxicity. CNS toxicity can be attributed to many causes therefore this dissertation describes personal and work-place characteristics that may impact symptoms, particularly emphasizing the effect of solvent exposure on CNS toxicity symptoms. Because prior research has established an association between solvent exposure, particularly PCE, and CNS toxicity symptoms, it is important for workers to engage in SWB to prevent CNS toxicity symptoms by further reducing exposure to solvents, such as PCE. Thus this dissertation developed and tested a conceptual model based on the HBM to determine the impact of perceived threat on engagement in SWB.

Key Findings

Chapter two reviews the existing literature on the association between low-level PCE exposure below 100 parts per million (ppm) and CNS toxicity symptoms. Fourteen of the fifteen studies reviewed found a positive association between PCE exposure and CNS toxicity symptoms, although dose response was not always established. The most commonly reported CNS toxicity symptoms were visual impairment, dizziness, motor-coordination impairment, attention deficits and memory loss. Three weaknesses of the current body of literature include: 1) inability to measure previous exposure, 2) lack of control for confounding variables such as stress and workload, and 3) inconsistency in measuring symptoms. The research, practice, and policy implications of the literature review findings are discussed.

The first study (Chapter three) investigated the prevalence of CNS toxicity symptoms in a sample of predominantly Korean (85%) dry-cleaner facility workers. Self-reported loss of visual perception, memory loss, tinnitus and dizziness were compared among workers in the high-exposure group (e.g., dry-cleaner operators and spotters) and low/ moderate-exposure group (i.e., all other job titles). Commonly reported CNS toxicity symptoms include loss of visual perception (23.1%), followed by dizziness (13.9%), memory loss (14.6%), and tinnitus (12.5%). Being in the high-exposure group, an owner, and use of PPE were associated with an increased risk of loss of visual perception and memory loss. After controlling for PPE use, workers in the high-exposure group were four times more likely (RRR=4.2; CI 0.9-19.6) to report memory loss and three times more likely (RRR= 3.4; CI 1.1-10.7) to report loss of visual perception compared to their counterparts in the low/ moderate-exposure group. Being an owner was the strongest predictor of CNS toxicity symptoms, however, 81% of owners worked in the high-exposure group. This finding may be explained by increased work hours, which may increase PCE exposure, or higher stress levels, which has been associated with memory loss (Stenfors, Hanson, Oxenstierna, Theorell, & Nilsson, 2013). Results of this study indicate that workers with exposure to below-PEL levels of PCE, particularly owners, may be at risk for experiencing CNS toxicity symptoms. More research is needed to substantiate these findings and determine whether very low levels of exposure to PCE (i.e., <10 ppm) are associated with symptoms of CNS toxicity.

The second study (Chapter four) utilizes the HBM to identify predictors of, and barriers to, SWB. The outcome of interest was whether perceived threat, as measured by perceived exposure sources and perceived susceptibility, could predict SWB. SWB is operationalized by engagement in PPB as defined by OSHA best practices and PPE use. Overall, engagement in

PPB was high (ranging from 80-92%). Work in the high-exposure group, being an owner, receiving training, and believing chemical exposure was harmful was associated with increased PPB scores. Use of PPE use was low among study participants (ranging from 14% for apron use- 56% for glove use) with discomfort being the primary reason for not using PPE. Being an owner and experiencing selected symptoms attributed to solvent exposure was associated with increased PPE use. It is interesting that predictors of PPE use and engagement in PPB were different. Perception of threat was a stronger predictor of PPB than PPE use and exposure group was only a predictor of PPB. Training was negatively associated with PPE use but positively associated with engagement in PPB. The minimal effect of perceived threat on engagement in SWB that was found in the current study should be further explored through longitudinal studies that have sufficient sample size to control for multiple possible confounders.

Policy, Practice, and Research Implications

Fourteen of the 15 studies reviewed found CNS deficits associated with PCE exposure below the current PEL. Furthermore, results from chapter three indicate approximately 48.5% of study participants reported at least one CNS toxicity symptom, with workers in the high-exposure group being most at risk for memory loss and vision loss. Taken together these findings indicate that the current PEL may not be protective of workers. Even though the current dry-cleaning workforce is likely exposed to PCE levels that are far below the PEL, OSHA should re-evaluate the current PEL and develop new guidelines to ensure the health of workers.

There are several practice implications for OHPs. OHPs should become knowledgeable about neurotoxicity hazards of PCE exposure for workers of dry-cleaning facilities. Furthermore OHPs should conduct an in-depth occupational and environmental health history as well assess for CNS toxicity symptoms in workers exposed to solvents. Tests of CNS toxicity should be sensitive to sub-clinical symptoms as, once symptoms appear, they may not be reversible (Gobba et al., 1998; Schreiber et al., 2002). Multidisciplinary care is key when there is a suspected case of CNS toxicity caused by solvent exposure. This involves client referral for further neuropsychological testing and requesting an industrial hygienist consult and potentially working with the local health department to address air quality concerns.

While the majority of the sample of dry-cleaners in this dissertation study engaged in OSHA best practices for reducing PCE emissions during the dry-cleaning process, only a small percentage of them used PPE. Interventions should focus on increasing the use of PPE, especially during maintenance and loading/unloading laundry. Of the modifiable predictors of PPB, only receiving training within the past year and perceived susceptibility were positively associated with increased PPB, therefore ensuring frequent training and education regarding health effects may increase prevalence of PPB. Although dry-cleaners using PCE are required to be inspected, current inspections mainly focus on sources of PCE emissions, rather than on creating safe work environments for workers. Governing agencies that do not already inspect for frequency of training and availability of PCE may benefit from adding this criteria to site inspections.

The literature review identified gaps in the current state of the science and recommendations for future research. Given lack of consensus in dose-response and duration-response, more research is needed. Researchers need to replicate previous research using standardized objective measures of CNS symptoms and should account for previous solvent exposure instead of focusing solely on recent measurements. Use of pharmacodynamic modeling should also be employed when possible in order to better aid in establishing dose response. Finally, studies should account for workload and stress levels, which may contribute to the presence of symptoms as well as to exposure levels. Future studies should expand beyond the dry-cleaning industry to see if workers in other industries are experiencing similar CNS toxicity symptoms.

Even though the current dry-cleaner workforce is exposed to much lower levels of PCE than in the past, more research is needed to ensure that workers are not at risk for CNS toxicity symptoms. In order to determine if CNS toxicity symptoms are reversible, it would be beneficial to conduct a longitudinal study of current and retired dry-cleaner facility employees with a control group to determine whether CNS toxicity symptoms they had while working at the dry-clearer facility would persist even after they stopped working.

To better understand predictors and barriers of SWB in dry-cleaners, future research should include a measure of self-efficacy, the belief that one has control over a situation. Other factors that should be controlled for include: presence of engineering and administrative controls, availability and frequency of use of PPE, safety culture and competing demands.

Strengths

A few strengths should be noted. The first strength of this research is the inclusion of immigrant population, who, due to language difficulties, would be excluded from other research. This is of particular importance in that immigrant workers make up a substantial portion of the dry-cleaning industry (Bureau of Labor Statistics, 2014). Second, while objective measures are preferred, use of self-report data captures injuries and work practices that were not captured by injury logs and work-site inspections. Last, to the author's knowledge, this study is the first study to use a theoretical framework based on the HBM to assess predictors of SWB in workers exposed to solvents.

Limitations

The study has several limitations that are related to lack of objective exposure measurement, lack of objective symptom assessment, sampling bias, inability to control for confounders, and issues with the application of the HBM constructs to the existing data.

First, lack of objective exposure measurement caused by the inability to differentiate true exposure levels between job titles was due to multiple reasons. The reference group is the low/moderate-exposure group. However, even the low/ moderate-exposure group can still be exposed to PCE (Gold et al., 2008). Workers were classified according to a single job title regardless of how many tasks they reported, but most workers had multiple duties and could have been exposed in one task but not in others. It is possible that workers may have rarely worked in the high-exposure task but still be classified as being in the high-exposure group. This limitation may contribute to misclassification bias. This study also did not evaluate if workers switched job titles during their tenure or account for exposure history. Finally, the exposure groups are classified based on data from the Echeverria et al. (1995) study, because there was no objective measurement of PCE exposure. Due to variability in facility workspaces and machine types, there can be variability in PCE exposure the study samples even though they performed the same tasks.

Second, lack of objective symptom assessment introduces bias. Data is based on self-report symptoms without objective clinical tests or examinations. This is especially problematic when measuring visual impairment as there was no differentiation between types of visual impairment (color vision loss, impaired visual contrast sensitivity, etc.). The frequency at which symptoms occurred was also not well defined, which may have impacted results. As this study is a secondary analysis, it is not possible to add this information after the fact.

Third, sampling bias limits ability to generalize study findings. Because these data were from a convenience sample, findings may not be generalized to the population of dry-cleaners, resulting in decreased external validity. Specifically, particular racial/ethnic groups and geographic areas are over-represented. Facilities' that agreed to participate in the study may have different work-site characteristics than facilities that did not participate. The sample size may have been too small, thus limiting ability to detect associations between exposure and CNS toxicity symptoms. One threat to internal validity is the healthy workers survivor effect, which posits that workers who are unable to tolerate the work environment do not remain employed in the same industry for a prolonged period of time, thereby increasing the likelihood of underreporting of adverse health conditions attributed to the work environment (Pearce, Checkoway, & Kriebel, 2007).

A fourth limitation is related to the lack of evaluation of potential confounders, including the differentiation between part-time and full-time workers. Full-time workers could have greater exposure to PCE than part-time workers. There was also no assessment of past solvent exposures or previous dry-cleaning machine use, both of which could contribute to current CNS toxicity symptoms.

Finally, because data for this data came from a secondary analysis, items regarding self efficacy and perceived benefits could not be included in this study. Previous research has found self-efficacy to be a strong predictor of SWB (Arcury et al., 2002; Ben-Ami et al., 2001; Glanz et al., 2002; Martinez et al., 2004). This study could also not measure the concept of perceived benefits, which is part of the original model. Finally, measuring health beliefs and behaviors at the same time can result in a spurious association between the variables (Glanz et al., 2002).

Conclusion

The majority of studies reviewed found an association between PCE exposure at levels below the current PEL and CNS toxicity. Despite this evidence, the current PEL has not changed. Policy makers and OHPs should continue to advocate for a more protective PEL, even though exposure levels have substantially decreased. This dissertation study findings indicate workers in the dry-cleaning industry may still be at risk for CNS toxicity symptoms. Therefore it is important workers continue to engage in SWB until solvent exposure can be further reduced or eliminated. Solvent exposure may contribute to the development of CNS toxicity symptoms. OHPs should include a thorough evaluation of exposure sources and sub-clinical symptoms in dry-cleaner workers and other workers exposed to solvents such as PCE. Being an owner and working in the high-exposure group were predictors of engaging in SWB. Perception of threat, as measured by perception of health effects and perception of exposure sources was a weak predictor of SWB. Experiencing symptoms associated with PCE exposure was also a predictor of PPE use. Organizational characteristics associated with engagement in SWB include size of facility and receiving training. Therefore, facility inspections should focus on type and frequency of training, and availability and use of PPE, in addition to evaluating sources of solvent exposure to further protect worker health. Through use of a multipronged approach, occupational health disparities related to solvent exposure can be reduced.

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