2018

Efficacy of Methods Available to Remove Environmental Tobacco Smoke in Vehicles

Brian Albert Nielson
Walden University

Walden University

College of Health Sciences

This is to certify that the doctoral dissertation by

Brian A. Nielson

has been found to be complete and satisfactory in all respects,
and that any and all revisions required by
the review committee have been made.

Review Committee
Dr. David Anderson, Committee Chairperson, Public Health Faculty
Dr. Jeanne Connors, Committee Member, Public Health Faculty
Dr. Simone Salandy, University Reviewer, Public Health Faculty

Chief Academic Officer
Eric Riedel, Ph.D.

Walden University
2018

Abstract

Efficacy of Methods Available to Remove Environmental Tobacco Smoke in Vehicles

by

Brian A. Nielson

MPH, Walden University, 2012

MAED, TUI University, 2009

BA, Concordia College, 1996

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Public Health – Community Health Promotion and Education

Walden University

August 2018

Abstract

Environmental tobacco smoke (ETS) is a serious public health threat. Residual ETS in vehicles unknowingly exposes future occupants to environmental tobacco smoke. Reducing or removing exposure to ETS has been proven to reduce long-term health complications. This quasi-experimental study investigated 5 cleaning methods and their effect on air particulate matter$_{2.5}$ ($PM_{2.5}$) along with the correlation between air nicotine levels and PM2.5 levels. Study variables included cleaning methods as the independent variable, and changes in air nicotine and $PM_{2.5}$ levels as the dependent variables. This study is framed within primary prevention and risk reduction based on the harm reduction theory. The harm reduction theory professes that when a hazard cannot be completely removed, methods to reduce the social and personal costs associated with the hazard should be developed. Fifty vehicles were placed in 5 groups: car wash vacuumed, shop vac vacuumed, air change, hand held vacuumed, and Hepa filtration air cleaned. Nicotine and $PM_{2.5}$ levels were measured before and after cleaning. A Wilcoxon ranked test analysis of the data showed all methods of cleaning studied had a statistically significant decrease in both air nicotine ($Z = -6.154$, $p < .001$) and $PM_{2.5}$ levels ($Z = -5.934$, $p < .001$). Kruskall-Wallis analysis showed no statistical significance between cleaning methods. Correlation analysis determined no correlation between nicotine and $PM_{2.5}$ (*r* value = <.3). Results of this study provides public health program professionals with information linking cleaning methods to reduction of exposure to ETS. Positive social change comes when programs are developed to training and education people to reduce their exposure, resulting in an increase in health and a decrease in medical costs.

Efficacy of Methods Available to Remove Environmental Tobacco Smoke in Vehicles

by

Brian A. Nielson

MPH, Walden University, 2012

MAED, TUI University, 2009

BA, Concordia College, 1996

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Public Health – Community Health Promotion and Education

Walden University

August 2018

Dedication

My parents had a great influence on my educational path and have always encouraged me to continue to learn. To this end, I would like to dedicate this research to my parents: Margaret Nielson and Leo Nielson. My father always inspired me to learn stating, “The one thing that cannot be taken from you is knowledge”. My mother inspired me to continue learning and has always had encouraging words. My parents instilled in me the ability to dream and set goals that often seemed out of reach but were always attainable, for this, I am forever thankful.

Acknowledgements

There are certain people who, through the process of completing the course work, conduction research, and the dissertation process, make the process achievable; I would like to acknowledge these people and thank them for their support.

First, I would like to thank my family. My wife, Deborah, who had to pick up many of the household chores and parenting needs while I spent countless hours in coursework and through the dissertation process. Without her support, this would not have been accomplishable. To my daughters, Taylor and Kathrynn thank you for understanding when I needed time to do course work and write my dissertation.

Next, I would like to thank those leaders who allowed me the latitude and time to complete the requirements of this degree. CDR Tiger Pittman, USS PENNSYLVNIA (SSBN 735) (GOLD), and CDR Kelly Laing, USS MAINE (SSBN (741) thank you for the time and encouragement you gave me. CDR Gregory Razniak thank you for your encouragement and belief in my abilities you set me on the path to accomplish this goal. To Command Master Chiefs Ben Stillwell and Kingsley Vanduzer, thank you for your understanding and the compassionate ear when I needed to vent during the stress of this goal.

Lastly to my dissertation committee; thank you Dr. David Anderson my dissertation chair and, Dr. Jeanne Connors my committee member you both challenged my abilities and made me work beyond what I thought were my limits. Without both of you, I would have never completed this program and achieved what I have.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction to the Study

Introduction

More than 3 decades of research has shown that chronic low-level exposure to secondhand tobacco smoke (SHS) is harmful to health, reducing life expectancy, and increasing medical costs (National Cancer Institute [NCI], 1999; US Department of Health and Human Services [HHS], 2006). Environmental tobacco smoke (ETS), also known as SHS, and third-hand smoke (THS), consists of both exhaled mainstream smoke and side stream smoke in the environment (Mueller et al., 2011). ETS is composed of a mixture of harmful particulate matter (PM), nicotine, carcinogens, toxicants, volatile organic chemicals (VOCs), irritants, and teratogens (Guerin, Jenkins, & Tomkins, 1992). Measuring PM of 2.5 microns ($PM_{2.5}$) diameter and nicotine have been proven representative of the levels of ETS in the atmosphere (ASTM, 2012; Guerin et al., 1992). According to the 2006 Surgeon General report (HHS, 2006), more than 50,000 deaths annually are attributed to ETS exposure; this includes 3,000 deaths from lung cancer, 46,000 deaths from coronary disease, and 400 from sudden infant death syndrome. Developmental delays in infants and children are linked to ETS exposure (Yolton, Dietrich, Auinger, Lanphear, & Hornung, 2005) as well as nicotine dependence in young children (Schuck, Kleinjan, Otten, Engels, & DiFranza, 2013).

When smoking occurs in vehicles, $PM_{2.5}$ and nicotine levels can reach have been measured as high as 3500ug/m^3 (Edwards, Wilson, & Pierce, 2006). Although these levels are reduced when the windows are open or when the cigarette is held outside the vehicle, $PM_{2.5}$ and nicotine levels remain significantly higher than ambient air (Edwards et al., 2006; Jones, Navas-Acien, Yuan, & Breysse, 2009). ETS is deposited into the vehicle's environment during and after smoking; when disturbed, ETS is re-aerosolized allowing occupants to be exposed (Fortmann et al., 2010; Jones et al., 2009; Matt et al, 2008; Mueller et al., 2011; Sendzik, Fong, Travers, & Hyland, 2009; Xu, Nemaollahi, Sextro, Gadgil, & Nazaroff, 1994). In vehicles where smoking was permitted, multiple studies have shown that $PM_{2.5}$ and air nicotine levels are considerably higher when compared with levels in vehicles where smoking was not permitted (Fortman et al., 2010; Matt et al., 2008; Offermann, Colfer, Radzinski, & Robertson, 2002). ETS levels remain elevated in the interior of a vehicle long after smoking has ceased, increasing levels of deposited ETS (Fortmann et al., 2010; Jones et al., 2009; Matt et al., 2008; Offermann et al., 2002). Research relating to methods to remove or mitigate exposure to ETS in the workplace, home, and other public places is available. However, no data address the effectiveness of methods to remove ETS from the interior environment of vehicles or methods to mitigate ETS exposure. Multiple studies have identified a gap in research regarding the removal of deposited ETS in vehicles (Fortmann et al., 2010; Matt et al., 2008).

Problem Statement

Occupants of vehicles where smoking has occurred are chronically exposed to low levels of ETS either by absorption through the skin, or by inhalation of re-aerosolized ETS (Fortmann et al., 2010; Hammer, Fischer, Mueller, & Hoefer, 2011; Matt et al., 2008). A large volume of research links low-level ETS exposure to adverse medical and mental health conditions (Dreyfus, 2010; He, Zhao, & Peng, 2013; Kramer et al., 2004; Kum-Nji, Meloy, & Herrod, 2006; Mannio, Moorman, Kingsley, Rose, & Repace, 2001; Yolton et al., 2005). These effects significantly increase in small children whose cells are rapidly reproducing, people who have underlying medical conditions, or people who are immunocompromised (Hammer et al., 2011).

The effectiveness of methods used remove ETS from the cabin of vehicles have not been studied. Without knowing how to remove ETS from a vehicle's interior, programs intended to protect the occupants of vehicles contaminated with ETS cannot be developed.

Purpose of the Study

My purpose in the quantitative study was to examine how commonly used cleaning methods affect residual ETS levels in the interior of vehicles as measured by $PM_{2.5}$ and air nicotine levels. This information is useful to public health and the community to develop methods and strategies to reduce exposure to ETS. This data will also be useful in the initiation of policy regarding what levels are acceptable in vehicles being sold. By providing efficacy, data and increasing individuals' perceived abilities to conduct the recommended behavior, more people may be inclined to protect themselves and those who ride in their vehicle; this research can provide information to increase individuals' perceived ability to conduct these cleaning techniques.

Nature of the Study

In this quantitative study, I explored ETS levels by monitoring air $PM_{2.5}$ and air nicotine levels before and after interior cleaning using different methods. In this quasi-experimental study, I used the case-control approach, collecting primary quantitative data; 60 vehicles were placed into six groups, one comparison, and five intervention groups. The independent variable for this study was cleaning method; the dependent variables were ETS and air nicotine level. All groups had 10 vehicles in them. The comparison group was composed of cars not exposed to ETS. This group was the baseline to demonstrate the effectiveness of cleaning. The data also established a baseline for ETS levels in uncontaminated environments. The efficacy of each cleaning method was determined by measuring the level of $PM_{2.5}$ in 20-liter air samples before and after cleaning.

Research Question and Hypothesis

Research Questions

RQ1: Through cleaning, can interior air quality of a vehicle be improved?

H_0: There will be no significant reduction in $PM_{2.5}$ or nicotine.

H_1: There will be a significant reduction in $PM_{2.5}$ or nicotine.

RQ2: How are residual $PM_{2.5}$ and air nicotine levels affected by different cleaning methods?

H_0: All means will be equal: $\bar{x}1 = \bar{x}2 = \bar{x}3 = \bar{x}4 = \bar{x}5$. There will be no significant difference in the reduction in $PM_{2.5}$ or air nicotine levels between groups.

H_1: Not all means will be equal: There will be a significant reduction in $PM_{2.5}$ or air nicotine levels in one or more of the groups.

RQ3: Is $PM_{2.5}$ an adequate representation of air nicotine levels?

H_0: $PM_{2.5}$ levels will change at a different rate than air nicotine levels; there is no correlation between $PM_{2.5}$ and air nicotine levels

H_1: $PM_{2.5}$ levels will correlate with air nicotine levels, both levels will change equally:

Theoretical Framework

The premise of this study was primary prevention (Gullotta, 1994), and risk reduction in the context of exposure to ETS. The harm reduction theory professes that when a hazard cannot be completely removed, methods to reduce the social and personal costs associated with exposure to a hazardous condition should be developed (Gullotta, 1994). Harm reduction theory is the background for many programs and policies. Programs such as the condom pass out and needle exchange have been effective in reducing the spread of HIV, and health effects associated with drug use (Stimson, 1998). Programs and policies regarding the safeguard of children in automobiles produced seatbelt and car seat laws and programs decreasing the number of children and infants dying in vehicle crashes (Savage, Kawanabe, Mejeur, Goehring, & Reed, 2002). Programs developed around the harm reduction theory do not remove the underlying hazard; instead, they implement change to reduce the influence the hazard has on life. In this manner, the goal of this research is to decrease the risk from ETS. Completely removing ETS from the vehicles is not possible; however, there may be some action available that will reduce the danger, or the amount of exposure received. Interventions based on the harm reduction theory are based on one of three levels: risk prevention, harm prevention, and harm containment. Risk prevention interventions include antitobacco campaigns, smoke free workplaces, and no smoking public space legislation (Zeller & Hatsukami, 2009). Harm prevention interventions include tobacco cessation programs and tobacco education programs (Stratton, Shetty, Wallace, & Bondurant, 2001). However, harm containment interventions include treatment for diseases related to tobacco smoke exposure (Gullotta, 1994).

In the risk prevention aspect of the harm reduction theory, two models are prevalent, the threshold response model, and the no-threshold model. Both the no-threshold and the threshold response models use background levels as a starting point. In the case of ETS, research has identified that even at low levels of exposure there are adverse medical and cognitive effects. No lower limits exist for ETS. Research has proven that even chronic low-level exposure is linked to undesirable medical outcomes (Dreyfus, 2010; He et al., 2013; Kramer, et al., 2004; Kum-Nji et al., 2006; Mannio et al., 2001; Yolton et al., 2005). When there are no acceptable levels of exposure the concept of As Low As Reasonably Achievable (ALARA) can be implemented as an acceptable level (Molhave, 2003). This research will be the background for programs and policies to reduce the social and personal cost associated with exposure to ETS.

Definition of Terms

The following terms are defined below for the current research.

Air nicotine: Nicotine that is airborne.

Body dose: The amount of a pollutant that is absorbed into the body, available to reach the target organ.

Chronic exposure: Exposure to a chemical, particulate or compound over a period greater than one month.

Chronic toxicity: The ability of a chemical at low levels over time to inflict organ, systemic or biochemical damage to the body.

Cotinine: The byproduct of nicotine breakdown within the body.

Environmental tobacco smoke: Primary and secondary smoke from the burning of tobacco deposited within the environment.

Effective biological dose: The amount of pollutant that is absorbed into the body and reaches the target organ.

Low-level: levels of a chemical or particulate that is within the permissible exposure limit as defined by the controlling regulatory agency, OSHA, EPA, or CDC.

Particulate matter: Solid and liquid droplet matter that remains suspended in the atmosphere, commonly referred to as pollutant.

Respirable particulate matter: any particulate or chemical of small enough diameter to reach the terminal ends, alveolar ducts, and alveoli. In microns, usually 10 or less

Third-hand tobacco smoke: Second-hand tobacco smoke deposited within the environment.

Toxic chemicals: Chemicals that have the ability to damage an organ, system or to disrupt a biochemical process.

Vehicle: Any device used for transporting persons where there is an enclosed cabin where occupants are seated.

Assumptions

I conducted this research with the following assumptions:

1. All tobacco smoked in the vehicles produced comparable PM.
2. Weather conditions during data collection will not affect the data obtained.

The first assumption was required so that each brand of tobacco used would not require independent studies for PM sizes. Research has shown that PM from smoking tobacco, regardless of the brand, falls into a narrow range (Guerin et al., 1992; Wang, et al., 2012). The second assumption was required to consider that were data to be collected on different days, with the understanding that control of the weather is not possible and waiting for the same environmental conditions would delay research. This second assumption was also required due to the fact data were collected outside and not in a climate-controlled environment.

Limitations

Several limitations existed in this study, including the population size and weather patterns. This study was limited to investigate the association between ETS levels and removal methods available at the time of the study. Not every vehicle type, body style, or interior material were studied; however, the results represent all vehicles. Weather could affect results; results from the same methods in different climates could provide different findings. Because I had access to data questionnaires and, therefore, knew the vehicles and the amount of smoking that occurred in each vehicle, there was the possibility of observer bias. This bias was minimized by me not collecting the data questionnaire, Appendix B, until after all samples were gathered, and using exacting procedures for gathering data so each sample was obtained, measured, processed, and documented in the same manner.

Strengths

This quantitative research derived its strength from the fact that I used primary data from a cross-sectional research design. Collection devices are industry standard and processing laboratories meet minimum criteria for national laboratory performance standards. Collection methods and sample handling methods will comply with guidelines set forth by the laboratory or the instrument manufacturer.

Significance of the Study

ETS-free environments can or may reduce chronic health effects (Dreyfus, 2010; He et al., 2013; Kramer, et al., 2004; Kum-Nji et al., 2006; Mannio et al., 2001; Yolton et al., 2005). Widespread knowledge of this fact is instrumental in developing public health programs to reduce smoking and increase individual and community health (Farkas, Gilpin, Distefan, & Pierce, 1999; Kramer et al., 2004; Kum-Nji et al., 2006; Mannio et al., 2001). ETS-free environments will contribute to improved general health resulting in reduced health costs, increased productivity, and an enhanced quality of life (Kum-Nji et al., 2006; Mannio et al., 2001; Kramer et al., 2004). This research could provide public health professionals as well as the community, additional information regarding the efficacy of methods to remove ETS from vehicle interiors.

Implications for Social Change

My findings could have the following influences on positive social change:

1. Stopping one person from being exposed to ETS.
2. Reducing the burden of medical costs.

By determining how to reduce the exposure to ETS this research can be used to decrease exposure to ETS. Reduction in exposure will reduce medical costs and the burden on medical care. This research promotes positive social change through reducing chronic low-level exposure to ETS. The results of this research will provide data necessary to educate people and communities on how best to remove ETS from vehicles. Like the education that reduced exposure to ETS in homes, workplaces, and public places to reduce chronic low-level exposure to ETS, this research focuses on reducing the levels of exposure and the effective biological dose from chronic low-level exposure to ETS in vehicles. Reduction in chronic low-level exposure to ETS will affect the entire society by reducing the number of chronic medical conditions and improving the health of the population.

Summary and Transition

TBS exposure in the United States identifies a true public health concern that has been minimally impacted by previous research, prevention, or intervention attempts outside of public places. Previous research has yielded a statistical association between exposure and increased cancers, respiratory complications developmental and cognitive slowing. However, reduction in

ETS exposure in vehicles has not yet been researched, a factor that may be the key to ameliorate this public health concern. An extensive literature review identified one gap in knowledge, the ability of the public to mitigate ETS exposure within a vehicle. My findings will help fill this gap. I used the case-control approach, collecting primary quantitative data to analyze the effectiveness of different methods used to mitigate ETS exposure in the confines of a vehicle cabin. My goal in this study was to determine the effect cleaning methods have on the levels of ETS in the cabins of vehicles where smoking has occurred. Although several limitations existed, strengths also existed. One strength was that I gathered primary data in a quasi-experimental designed study. A second strength was that I evaluated air nicotine levels and air $PM_{2.5}$, which represent actual respirable levels of both

Identification of methods to reduce ETS exposure in vehicles is significant in reducing ETS exposure and thus decreasing related illnesses. The results of this study could identify contributing factors and at-risk populations, as well as provide a framework for future research in ETS research to meet the goals of the Healthy People 2020 objectives.

Organization of the Study

In Chapter 2, I provide a review of the relevant literature, outline the influence of tobacco and ETS on modern society including a comprehensive review of the literature on ETS and ETS-related illnesses, as well as PM and its properties as related to ETS. In Chapter 3, I outline the quantitative methods approach to include the population, sample, setting, instrumentation, data collection, data analysis, and the method for protecting the participant’s privacy. Chapter 4 is my review and analysis of the data collected related to each research question. I discuss my interpretation of the findings, limitations and implications of the study, recommendations for future research and my conclusion in chapter 5 discusses

Chapter 2: Literature Review

Purpose of the Study

My purpose in this study was to examine how commonly used cleaning methods affect residual ETS levels in the interior of vehicles as measured by $PM_{2.5}$ levels. This information will be useful to public health and the community to develop methods and strategies to reduce exposure to ETS. This data will also be useful in the initiation of policy regarding what levels are acceptable in vehicles for sale. By providing efficacy, data and increasing individuals' perceived abilities to conduct the recommended behavior more people may be inclined to protect themselves and those who ride in their vehicle. This research can provide information regarding methods to reduce ETS exposure.

Introduction

The literature review that I conducted for this study used multiple literature repositories, including PubMed, MEDLINE, Google Scholar, and Academic Premier (EBSCO) to ensure a comprehensive review. Appropriate keywords including *second-hand tobacco smoke*, *third-hand tobacco smoke*, *environmental tobacco smoke*, *tobacco smoke*, and *vehicle* were used. Review criteria limited articles to those published within the last ten years, available in English, published in peer-reviewed journals, and available in full PDF format. I selected articles relating to ETS, health effects of ETS, ETS in vehicles, measurement, and discrimination of PM, and ETS behaviors in closed spaces. I included earlier articles if no newer research related to ETS, and the research was deemed relevant. In this chapter I provide a discussion of current literature related to, the history of tobacco use, tobacco related diseases, components of ETS, measuring ETS, levels of ETS in vehicles, and a review of the theoretical basis.

Review of the Problem

Occupants of vehicles where smoking occurs are chronically exposed to low levels of ETS. Exposure is through skin absorption, or by inhalation of re-aerosolized ETS (Fortmann et al., 2010; Hammer al., 2011; Matt et al., 2008). Matt et al. (2008) studied 120 vehicles and found that in vehicles where smoking was allowed, nicotine levels were 37.2 times higher than vehicles where smoking was not allowed. These levels remained significantly elevated for up to six months after smoking ceased (Matt et al., 2008). A large volume of research linking low-level ETS exposure to adverse respiratory diseases such as emphysema, and asthma (Kit, Simon, Brody & Akinbami, 2013). Research links ETS to delayed mental development and nicotine addiction (Dreyfus, 2010; He et al., 2013; Kramer et al., 2004; Kum-Nji et al., 2006; Mannio et al., 2001; Yolton et al., 2005). These effects significantly increase in small children whose cells are rapidly reproducing, people who have underlying medical conditions, or people who are immunocompromised (Hammer et al., 2011). Efficacy and methodology of ETS cleaning have not been studied regarding ETS levels. Without knowing how to remove ETS from a vehicle's interior, vehicle owners and public health officials cannot protect the occupants of vehicles contaminated with ETS.

History of Tobacco Use

Modern tobacco use is traceable to 1760, with the first processing plants being built in New York by Pierre Lorillard (Grob, 2011; MacKay & Eriksen, 2002). In its infancy, tobacco was thought to be a cure for over 30 health problems. Nicotine was discovered in 1826 and was determined to be a dangerous poison; in 1836 Samuel Green determined that tobacco was in insecticide and a poison (MacKay & Eriksen, 2002) Until the early 1900s, cigars were the main tobacco products sold; however, by 1913, cigarettes would become the number one tobacco product (Borio, 2011; MacKay & Eriksen 2002). The first step toward the regulation of tobacco sales was the 1964 Surgeons General report on the health hazards of smoking (Boria, 2011, Grob 2011). By 1966, health warnings were required to be added to each pack of cigarettes sold and by 1971 cigarette ads were no longer on television (MacKay & Eriksen, 2002). In 1982, the Surgeon General reported that second-hand tobacco smoke caused lung cancer (HHS, 2006). By 1990, smoking was banned on all flights except those to Alaska and Hawaii, and these were included by 1992 (MacKay & Eriksen, 2002). In 2000, smoking in public places was banned (Grob, 2011; HHS, 2006) and in 2012 smoking was banned on by the United States Submarine Force (G. Raczniak, personal communication, September 18, 2012).

Tobacco Related Disease

In the United States, approximately 50,000 people die each year from diseases related to second-hand smoke exposure (HHS, 2006). In addition to this, second-hand smoke exposure causes other medical conditions that reduce life expectancy and increase medical costs (HHS, 2006). In 2006, the U.S. Surgeon General also noted that the only way to reduce the incidence of ETS-related illness and death is to provide smoke-free environments (HHS, 2006).

Jaakkola and Jaakkola (1997) studied how dose, time of exposure, place of exposure and length of exposure related to the biological effective dose and the long-term outcome of exposure to ETS. Figure 1 shows the relationship between these factors to determine the final effective dose. This research shows that the time in the life cycle when exposure happens is just as important as the amount of exposure. If a person is exposed to the same level of ETS early in life and periods where the immune system is compromised there would be greater biological effective dose. Jaakola and Jaakkola (1997) also found that exposure to very low levels of ETS could amount to a large biological effective dose if the exposure happens over an extended period, months to years.

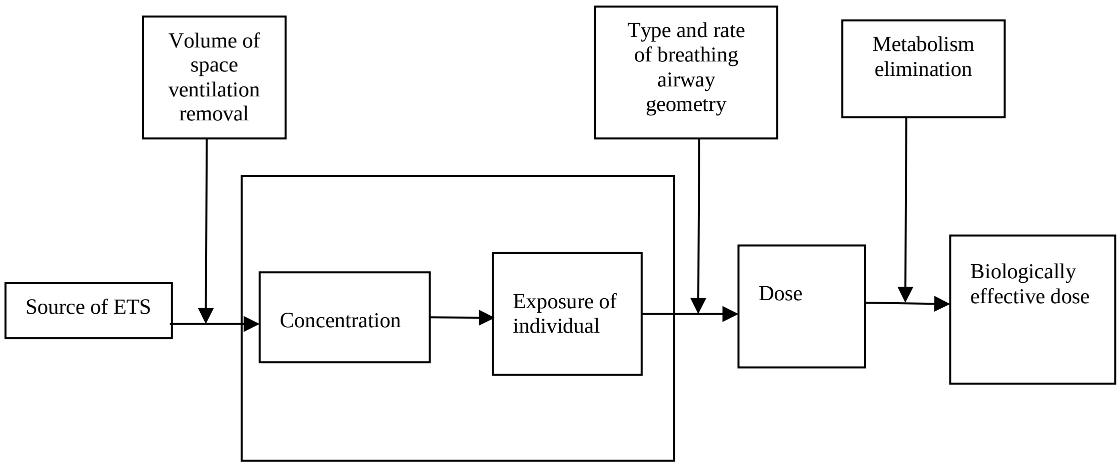

Figure 1. The chain of elements that lead to exposure of an indiviual to environmantal tobacco smoke (ETS) and the factors that determine the resulting dose to the human bidy and the biological effective dose. Jaakkola and Jaakkola, 1997, *European Respiratory Journal*, *10*, 2384-2397.

Chilmonczyk et al. (1993) in the study of 204 children, found a dose-dependent exacerbation of asthma related to urine cotinine levels. As the participant's urine cotinine levels increased, so did the number and severity of asthma attacks. Urine cotinine levels in the participants exposed to ETS were 2-10 times higher than nonexposed participants. In the exposed group, the relative risk for asthma attacks was increased by1.8 times (95% CI, 1.4-2.1), although Chilmonczyk et al. (1993) determined that there is a dose-dependent exacerbation of asthma regarding nicotine exposure. Comhair et al. (2011) conducted a 10-center study from 2002 through 2006 evaluating 654 asthmatics and determined that the severity of asthma attacks increases as exposure to ETS increases. They found that asthmatics exposed to ETS had more frequent and more severe asthma attacks than asthmatics not exposed to ETS. Researchers also identified that exposure to ETS by asthmatics; increased the frequency of use of rescue medication, reduced lung functions, and a reduced response to bronchodilators; this resulted in a decreased quality of life score on the Juniper quality of life questionnaire (Comhair et al., 2011). Asthmatics exposed to ETS had 2.1 times higher likelihood of having restricted airflow before an attack, and 15.3 times higher likelihood that the attack would be severe (Comhair et al., 2011).

In a 2001 study, Castelao et al. (2001) identified that smokers had 2.5 times greater increase in the incidence of bladder cancer than those that never smoked. Castelao et al. (2001) also identified that women exposed to ETS had a significantly higher incidence of bladder cancer compared to their male counterparts. McCarville, Sohn, Oh, Weiss, and Gupt (2013) found that while ETS exposure was related to more frequent asthma attacks (1.3 times greater incident ratio), and more severe attacks they also noted that the urine cotinine levels were more accurate in determining exposure than household reporting.

Kramer et al. (2004) enrolled 1,669 children beginning school, average age 5 to 6 years, evaluated by trained medical professionals using a standardized skin evaluation as well as skin prick sensitivity tests. Urine cotinine levels for participants were determined. A comparison of dermatological and sensitivity results compared to cotinine levels was performed. The results of this study showed that as urine cotinine levels increased, equated to ETS exposure, atopic eczema diagnosis increased as did skin sensitivities. An increase in urine cotinine levels of 100ng/mg^{-1} related to an odds ratio of 1.97, with a 95% confidence interval.

Multiple studies used data from the Third National Health and Nutrition Examination (NHANES III) (1994) database to research ETS exposure to medical conditions. Mannio et al. (2001) used data from the exposure to determine if prenatal maternal or postnatal exposure to

ETS influenced the respiratory health of the child. Children age 4 to 16 years who had serum cotinine levels drawn were the population of this study. Of the 13,944 participants in the original study, 5,400 were included in this study. The study identified that ETS exposure increased the risk for asthma by 5.3% with a 95% confidence interval, as well as an increase in wheezing not associated with a cold by 4.8%. Lung functions were also significantly decreased in participants who had increased serum cotinine.

Children exposed to ETS suffer cognitively as well as medically. Yolton et al. (2005) used data from the NHANES III to investigate the relationship between ETS exposure and cognitive abilities. This study included 6365 of the original population. Participants were age 6 through 16, who had serum cotinine levels determined and were between minimum detectable (0.035ng/ml) and 15ng/ml, which relates to active smoking. Average cotinine level was 0.23ng/ml. These participants also completed various cognitive testing. When adjusted for socioeconomic factors cognitive test scores showed an inverse relationship between ETS exposure and cognitive skills scores. The higher the cotinine levels, the more pronounced the relationship. This relationship was noted even at very low levels of ETS exposure. Reading scores decreased 5.0 points with each 1ng/ml increase in cotinine. Increased cotinine levels related to a decrease in cognitive scores in math, reading and visuospatial reasoning; however, there was no significant detriment to short term memory identified.

Fetuses are exposed to ETS because nicotine crossing the blood placenta barrier. Pichini & Garcia-Algar (2006) studied newborns exposed to in utero tobacco smoke. This research identified that newborns exposed to ETS in utero developed nicotine addiction and displayed withdrawal symptoms after removal from the environment. These symptoms included tremors, disturbances in sleep patterns, and irritability. The research identified a direct relationship between exposure levels and withdrawal symptoms. The newborns exposed to the highest levels of in utero smoke showed symptoms similar in nature to a smoker going through withdrawal. Schuck et al. (2013) studied 778 children from 15 Dutch schools aged 9-12 who had never smoked and who were exposed to ETS in the home; 8% of the participants reported the want to start smoking and 20% of the participants had withdrawal symptoms when ETS was absent.

In a study of zebra fish embryos, Hammer et al. (2011) determined that ETS contact by the human skin causes significant exposure to nicotine. This study identified that smoke that was bound in permeable materials was transferable through the skin. A component of ETS is nicotine; therefore, exposure to ETS would also include exposure to nicotine. Exposure to ETS can come from contact with contaminated textiles, including those similar to the upholstery in vehicles (Hammer et al., 2011).

According to Farkas et al. (1999), ETS exposure increased failure rates for persons trying to quit smoking. They studied 48,548 smokers who did not live alone and tried to quit in the preceding 12 months. This study identified that those who worked and lived under a partial smoking ban had a 1.83% greater quit ratio than those who lived with a smoker. Farkas et al. (1999) also noted that those who lived and worked under a total smoking ban had a 3.86% greater quit ratio when compared to those who lived with or worked in a smoking environment.

These diseases and medical conditions cost the medical system millions of dollars each year, along with thousands of lost workdays (HHS, 2006) and negatively impact the quality of life of those exposed (Comhair et al., 2011). According to the Centers for Disease Control and Prevention, there were over 443,000 premature deaths, from 2000-2004, attributed to cigarette smoking and exposure to tobacco smoke (Centers for Disease Control and Prevention [CDC], 2008). Exposure to tobacco smoke and smoking also resulted in 5.1 million years of potential life lost during the same period (CDC, 2008). The disease burden on productivity for this same period is $96.8 billion in lost productivity annually (CDC, 2008). Mortality attributed to secondhand smoke according to the CDC (2008) is 49,400 deaths annually.

Components of Environmental Tobacco Smoke

Production of ETS happens during the puffing and exhalation of tobacco products and from the burning of tobacco products between puffs, called sidestream smoke (Guerin, et al., 1992). According to Guerin, Jenkins & Tomkins (1992), ETS is composed of seven main components: nicotine, carbon monoxide, nitrogen oxide, formaldehyde, aromatic hydrocarbons, volatile organic compounds, and PM. Most of these are normal air contaminants and therefore not distinguished as unique to ETS (Guerin et al., 1992). Only one item is unique to ETS, nicotine, and numerous studies document high levels of nicotine in ambient air of vehicles where tobacco is smoked (Apelberg et al., 2008; Matt et al., 2008; Matt et al., 2013).

Particulate Matter

PM is the term used to identify the mixture of liquid droplets and solid particles found in normal air (EPA, 2015). PM is further classified as inhalable coarse PM, those items greater than 2.5 micrometers and smaller than 10 micrometers in diameter; and fine PM, items smaller than 2.5 micrometers (EPA, 2015). PM is generated from multiple different sources. The particles are differentiated as primary or secondary particles; primary particles come directly from the source, whereas secondary particles are formed from reactions in the atmosphere. Many primary particles are of the course size. However, most of the fine particles are comprised of secondary particles (EPA, 2015).

Most of the PM from tobacco smoke is similar to other air contaminants. However, only ETS, diesel exhaust, and talcum powder produce PM through the range of 0.01 through 1.0 micrometers (µm). This makes PM from tobacco smoke different enough to be able to differentiate ETS from other ambient air contaminants; Figure 2 illustrates particulate size distribution from different contaminants.

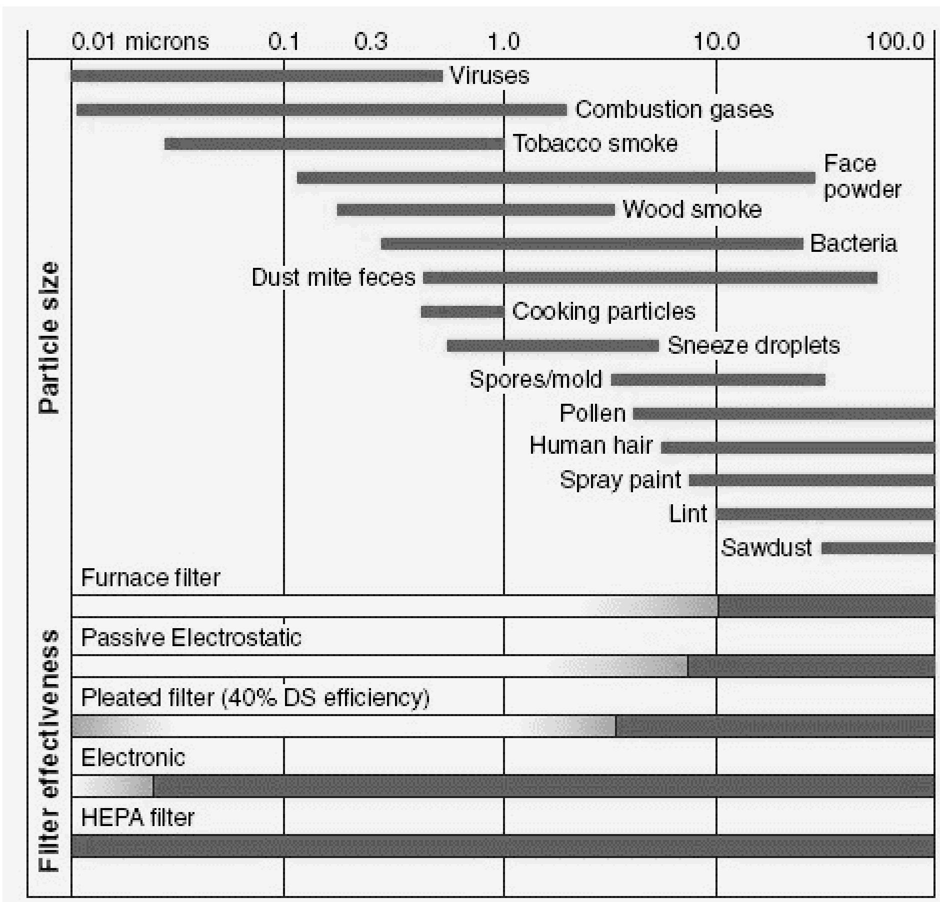

Figure 2. Air Filtration vs. particulate size. Adapted from "Best Practices Guide to Residential Construction: Materials, Finishes, and Details." S. Bless 2005. Copyright 2005 by John Wiley and Sons.

Invernizzi et al. (2004) studied PM produced from cigarettes and diesel exhaust and determined that ETS and diesel exhaust are similar in that they are both comprised of PM, hydrocarbons and VOC (Inveness et al., 2004). PM produced by both diesel exhaust and ETS are similar in that they both produce PM_{10}, $PM_{2.5}$, and PM_1. However, when compared to PM in ambient air, ETS from 4 cigarettes smoked produces seven times more PM_{10}, ten times more $PM_{2.5}$, and 12 times more PM_1 than diesel exhaust form a vehicle that is idling for 60 minutes, in the same space (Inveness et al., 2004).

An accurate representation of ETS can be determined by monitoring PM 2.5 micrometers (µm) ($PM_{2.5}$) in the atmosphere (Apelberg et al. 2008; Klepeis, Ott, & Switzer, 2007; Morawska, Jamriska, & Bofinger, 1997). Constituents of ETS are detectable from 0.5 µm to greater than 50µm. PM is categorized by how far down the respiratory tract they can reach (Brown, Gordon, Price, & Asgharian, 2013). PM larger than 10µm is considered inhaled particulates and remains in the extrathoracic airways meaning these particles do not pass beyond the larynx (Brown, et al., 2013). PM smaller than 10µm is considered thoracic, reaching smaller airways. While PM with a diameter of 2.5µm is considered respirable and is carried to the lower portions of the lungs and causes damage to the respiratory system. (Brown et al., 2013; Xing, Xu, Shi, & Lian, 2016). $PM_{2.5}$ has a smaller diameter; however, it has a larger surface area and is capable of carrying other toxic chemicals (Xing, et al., 2016). Research has validated that $PM_{2.5}$ is uniquely representative of ETS in the environment (Apelberg at al., 2008; Guerin et al., 1992; Offermann et al., 2002). $PM_{2.5}$ has been used in multiple studies to identify and measure ETS (Edwards et al., 2006; Klepeis et al., 2007; Morawska et al., 1997; Zhang et al., 2005). Given this, $PM_{2.5}$ will be used to represent ETS in this study.

Volatile Organic Compounds

Tobacco smoking produces VOC's which are dispersed in the environment (Guerin, Jenkins, & Tomkins, 1998; Wang et al., 2012). There are over 4,000 VOC's that are produced from the burning of tobacco smoke (Guerin et al., 1998). New vehicles have a large number of VOC's from the production process and many of which are similar to those produced from tobacco smoke (Ke-win et al., 2007). Both airflow and temperature affect the quantity and type of VOC's that are present in vehicles (Ke-win et al., 2007; Fedoruk & Kerger, 2003). No single VOC has been identified as a marker for tobacco smoke, and many of the VOC's found in new vehicles are also identified within tobacco smoke (Ke-win et al., 2007; Fedoruk & Kerger, 2003; Guerin et al., 1998).

Nicotine

Nicotine ($C_5H_4NC_4H_7NCH_3$) a chemical present in tobacco; smoking tobacco releases nicotine into the environment as vapor (Guerin et al., 1998). Nicotine can be absorbed through the lungs or the skin; no matter how nicotine is absorbed, it stimulates a parasympathomimetic response; as such, it activates cholinergic receptors in the brain (NLM, 2015). Nicotine is natural in the tobacco plant and makes up 0.6 - 3.0% of its dry weight (Wang et al., 2008). The concentration of nicotine in tobacco leaves is dependent on nitrogen levels in the ground in the early stages of growth, and removal of the axillary buds in mature plants (Wang et al., 2008). OSHA has determined a permissible exposure level 8-hour Time Weighted Average (TWA) for the workplace of 0.5mg/m3 (OSHA, 2016). No safe level of airborne respirable nicotine has been determined, however, the Surgeon General has stated that no level of ETS exposure is acceptable (HHS, 2006). ETS exposure varies the extent of smoking in the vehicle, and the time occupants spend in the vehicle (Fortman et al., 2010).

Much research has been conducted measuring nicotine in SHS and ETS. Agbenyikey et al., (2011) studied $PM_{2.5}$, and air nicotine levels, in public places where there were no smoking bans. They identified a strong correlation between $PM_{2.5}$ levels and air nicotine levels. This research shows that in an environment where there is known ETS $PM_{2.5}$ is an accurate measurement of ETS levels, and that exposure to $PM_{2.5}$ correlates to nicotine and ETS exposure. Anderson (2004) studied how $PM_{2.5}$ and nicotine levels compared in smoking-allowed and non-smoking areas throughout the Denver area. Higher $PM_{2.5}$ levels had a higher correlation to ETS (0.62%) than the lower $PM_{2.5}$ levels (Anderson, 2004). For this reason, air nicotine levels will be measured to determine if cleaning reduces air nicotine levels at a similar rate as $PM_{2.5}$ or if the two are reduced at differing rates and by different methods.

Measuring Environmental Tobacco Smoke

There is abundant research regarding the measurement of ETS. Research conducted by Jaakola and Jaakola (1997) began to identify methods to measure ETS in the environment. Jaakola and Jaakola (1997) determined guidelines that newer research followed in the measurement of ETS. They determined that there needed to be both qualitative and time specific measurements of ETS. They also identified that there were two indicators that could be measured to identify levels of ETS, they determined that nicotine and respirable suspended particulates (RSPs) were the best indicators of ETS levels.

There are two methods that are accepted as accurate for measuring nicotine in the environment. Nicotine can be measured with passive monitors, or active monitors (Apelberg et al., 2008). Both methods measure nicotine by absorbing the nicotine in a medium that absorbs the nicotine and processed by a laboratory at a later time (Apelberg et al., 2008). There is no real-time monitoring available for nicotine (Apelberg et al., 2008).

Jaakola and Jaakola (1997) found that stationary monitoring of RSP's was the most effective method to measure levels of ETS in microenvironments. Nazaroff and Klepers (2003) conducted a review of research and found that ETS-RSP's are mainly of the particulate size of 0.1-2.5 µm they also identified that while particles of this diameter stay aloft longer and do deposit in the environment, this particle size is difficult to remove by filtration (unless a HEPA filter is used). Chin et al. (2009) studied how nicotine levels and $PM_{2.5}$ levels were related; they determined that nicotine levels in a standalone filter were statistically similar to nicotine levels monitored in conjunction with monitoring for $PM_{2.5}$. Research by Chin et al. (2009) laid the groundwork for researchers to determine ETS exposure by correlating $PM_{2.5}$ levels to nicotine and ETS levels. Real-time monitoring of ETS is accomplished using a personal aerosol monitor, measuring $PM_{2.5}$. (Rees, & Connolly, 2006). When placed at the level of the headrest of an automobile, $PM_{2.5}$ levels are representative of occupants' exposure levels (Ke-wei et al., 2007; Matt et al., 2014; Rees, & Connolly, 2006). Levels monitored at the level of a car seat in the rear seat represent exposure levels of children (Ke-wei et al., 2007; Offerman, et al., 2002).

Levels of Environmental Tobacco Smoke in Vehicles

Hammer et al. (2011) conducted research related to residual ETS in textiles. Hammer et al. (2011) identified that up to 50 percent of deposited ETS on non-porous surfaces and in the porous materials are absorbed through human skin. (Fortman et al., 2010; Matt et al., 2008; Offermann et al., 2002). Matt, Bernet, and Melborne (2008) studied ETS levels in vehicles; they noted that PM from ETS-contaminated porous materials within the environment was re-aerosolized, thus allowing for inhalation of ETS. In another study, Semple et al. (2012) measured SHS exposure, measured as $PM_{2.5}$ levels of 17 participants over 104 rides in vehicles both where there was active smoking and where the vehicle had been smoked in prior. They found the average SHS exposure in vehicles during these trips during the non-smoking trips was 13µg/m^3 with a range from 2.6-43µg/m3. These $PM_{2.5}$ level measurements were taken in the passenger's seat at the headrest and in the rear seat at the level of a child's nose.

Matt et al. (2014) evaluated 250 rental cars measuring dust nicotine $PM_{2.5}$, air nicotine, and surface nicotine at the time of rental. At rental, dust nicotine levels in these vehicles ranged from 9.2 µg/m^3in vehicles that were rented as smoke-free to 33.7 µg/m^3in smoking allowed vehicles; maximum levels were 936.5 µg/m^3. In a 2008 study, Matt et al. measured ETS levels in 107 vehicles advertised for sale, they measured dust nicotine, measured as $PM_{2.5}$. $PM_{2.5}$ exposure levels in non-smoker's vehicles ranged from 0.2µg/m3 – 20.3µg/m3, with an average of 3.37µg/m3. In smoker's vehicles, dust nicotine levels ranged from 3.36µg/m3 – 36.28µg/m3, with an average of 11.61µg/m3. Vehicles with smoking bans, ETS ranged from 14.51µg/m3 to 26.12µg/m3, with an average of 19.51µg/m3.

Offeramnn et al. (2002) evaluated $PM_{2.5}$ levels in a vehicle under different driving and ventilation conditions. They found that ventilation conditions, such as window open and closed condition did affect the levels of ETS in the vehicle. However; even with the driver's window down, levels of ETS were three times higher during smoking. With the fan on, the levels were even higher- showing that deposited ETS in the ventilation system contributed to higher levels.

With the windows closed, the ETS levels were over 300 times higher than those in homes that allowed smoking.

Matt et al. (2008) in their study of used cars for sale smoker's vehicles had significantly higher levels of ETS even after being cleaned. Their research included 40 nonsmokers' and 87 smokers' vehicles. To be considered a smoker's vehicle the owner had to smoke at least one cigarette per week in the vehicle. They found that air, dust, and surface nicotine levels were elevated in all smoked in vehicles; however, dust and surface levels were significantly higher than air levels. They were able to, with 99% accuracy; determine the difference between a smoked in vehicle and non-smoked in vehicle.

Quintana, et al. (2013) analyzed five studies investigating the ability to identify smokers' cars. With a threshold of 0.1 $\mu g/m^2$, they noted that with over a 74% reliability they were able to identify smokers' cars even after months of not being smoked in, by measuring $PM_{2.5}$ levels and nicotine swipe levels. This research did not identify the cleaning methods or the $PM_{2.5}$ and nicotine levels before and after cleaning.

Conceptual Framework

Primary prevention

The concept of primary prevention is to protect healthy people from becoming ill or injured (Gullotta, 1994). Primary prevention includes those actions taken to prevent exposure to, reduce exposure to, or minimize effects from exposure to harmful substances or environments. Primary prevention includes protecting both healthy persons and persons who may have pre-existing conditions from ETS. Providing a healthy environment is one aspect of primary prevention.

Public health relies on three stages of prevention; primary, secondary and tertiary (Donovan, McDowell, & Hunter, 2008). Public health applies the stages of prevention at different stages of diseases to either prevent the disease, minimize disease impact (Donovan et al., 2008). Primary prevention's focus is the prevention the onset of disease. The focus of secondary prevention is the detection and treatment of pre-clinical disease (Donovan et al., 2008). Tertiary prevention focuses on minimizing the impact of diseases (Donovan et al., 2008).

Public health efforts utilizing primary prevention include the vaccinations, fluoride in drinking water, tobacco cessation programs, DARE programs, drivers' education, and public lake water testing (Floyd, Prentice-Dunn, & Rogers, 2000). The focus of primary prevention is the prevention of a disease through risk reduction. Risk reduction is achieved through; removing or reducing disease agent, changing behavior, reducing the risk, or boost the resistance to the disease agent (Floyd et al., 2000). Removing second-hand tobacco smoke from the environment reduced the exposure to second-hand tobacco smoke, thus reducing the risk of tobacco-related illnesses (O'Neill et al., 2003). Current legislation regarding smoking in vehicles while children are present is another example of primary prevention (O'Neill, et al., 2003). Reducing the exposure to tobacco smoke in children reduces their risk to those same tobacco-related illnesses (O'Neill et al., 2003). Other examples of primary prevention include tobacco cessation courses and health warnings placed on tobacco packaging (Floyd et al., 2000; O'Neill et al., 2003).

Harm reduction theory

Harm reduction theory is a framework through which a reduction in social and personal harm is reduced through an activity or program, when the strict abstinence of the drug or chemical is not considered achievable (Lenton, & Single, 1998; Zeller, & Hatsukami, 2009). Harm reduction, as defined by Lenton and Single (1998) is:

> Any policy, program or intervention as being one of harm reduction if, and only if: (1) the primary goal is the reduction of drug related harm rather than drug use per se; (2) where abstinence-orientated strategies are included, strategies are also included to reduce the harm for those who continue to use drugs; and (3) strategies are included which aim to demonstrate that, on the balance of probabilities, it is likely to result in a net reduction in drug-related harm. (p. 216)

In ETS, harm reduction the goal is to reduce the social and personal impact of ETS (Zeller, & Hatsukami, 2009). According to Jaakkola, & Jaakola (1997), there are two components to dose, concentration of the chemical and length of exposure. Under the harm reduction theory, programs or policies should be directed towards lowering one or both of these components (Zeller, & Hatsukami, 2009).

The harm reduction theory has been utilized to reduce infant and child injuries due to improper use of restraints. Since it is impractical to stop allowing children and infants to ride in vehicles, research was conducted, and programs were developed, and policies implemented to ensure proper child restraints were used. In 1983, Michigan enacted compulsory child safety seat use, Wagenaar and Webster (1986) studied the impact of this law on child safety seat use and injuries from automobile accidents. After Michigan's compulsory use law had taken effect, seat belt and child seat use increased 299% from 12% in 1982 to 51% in 1983, during the same period the number of injuries decreased by 25% (Wagenaar & Webster, 1986).

Summary and Transition

Chapter 2 was a review of current literature regarding ETS, PM, air nicotine and tobacco-related illnesses as well as the association between ETS and air nicotine and PM levels. In chapter 2 I also discussed literature relating to the every-dose theory, and the concept of ALARA. Research suggests that exposure to ETS causes respiratory illnesses, an increase in skin conditions, cardiovascular insult, and mental development delays. Public health has utilized primary prevention in tobacco cessation programs, legislation restricting tobacco smoking in public buildings, and most recently to stop exposure in vehicles by making it an offense to smoke while a child is present in the vehicle. This research will begin to gather the data required to make recommendations on the best method (s) to remove dust ETS from the cabin of vehicles, achieving ALARA and providing an environment where the occupants are not being exposed to the carcinogenic effects of ETS.

In chapter 3 I discuss the methodology used in this study. This includes discussion related to the study design, tools utilized, and procedures used to gather data. Applications used in the analysis of the data are discussed in detail in chapter 3 as well as methods to safeguard data. In chapter 4 I review and analyses the data collected relating to each research question. I discuss my interpretation of the findings, limitations and implications of the study, recommendations for future research and my conclusion in chapter 5.

Chapter 3: Methodology

Introduction

Occupants of vehicles where smoking has occurred are chronically exposed to low levels of ETS either by absorption through the skin or by respiration of $PM_{2.5}$ contaminated with ETS. In Chapter 3, I discuss the study design, study population and sample size, data collection method, method of data analysis, and recruiting methods.

Purpose

My purpose in this research was to gather data to build awareness regarding how effective ETS remediation efforts are for the confined space of a vehicle. Other possible outcomes from this research include:

1. This research can increase knowledge within the public health profession regarding ETS levels and exposure to passengers of motor vehicles.

2. This research can begin the dialogue for applying the concept of ALARA to ETS.

3. This research can lay the foundation for future research to best practices in a reduction of the total ETS exposure individuals receive.

Study Design

In this quantitative cross-sectional study, I gathered primary data related to ETS in vehicles interiors before and after cleaning, is designed using a nonequivalent (pretest and posttest) control group design. The nicotine and $PM_{2.5}$ levels gathered before cleaning are considered the baseline, the cleaning performed is the intervention and the levels of nicotine and $PM_{2.5}$ after cleaning show a response to the intervention. I collected nicotine and $PM_{2.5}$ levels and analyzed to determine how nicotine and $PM_{2.5}$ levels respond to cleaning, if levels respond in a similar manner, and whether the levels reduce significantly. The change in air nicotine and $PM_{2.5}$ level was the dependent variables, whereas the cleaning method was the independent variable.

Population

The population for this study was vehicles that were recently smoked in. Exclusion criteria were as follows: open air vehicles (convertibles or vehicles with no tops), vehicles used to carry chemicals within the cabin, and vehicles used for agricultural or industrial purposes, and vehicles whose owners do not know when smoking has taken place in the vehicle. I chose these criteria to ensure the levels being measured were from tobacco smoke and not from another similar chemical.

Sample

The sample size was set at 60 vehicles, 10 comparison vehicles and 50 study vehicles. I randomly placed accepted vehicles in one of 5 groups. Determination of sample size used the local population of 260,131 (U.S. Census Bureau, 2015) and a confidence level of 95% and a confidence interval of 18. Grouping of vehicles was by the time/date that they are accepted into the study. The comparison group was comprised of 10 vehicles from a local dealership. Only one set of samples was taken in the comparison group and this group did not have and intervention conducted on it.

Setting

The research was conducted in Bremerton, Washington, a city within Kitsap County, located on the Olympic Peninsula in western Washington. The region has a large number of smokers and is home to the Naval Base Kitsap, which is the base homeport to two aircraft carriers, three surface ships, and 15 submarines as well as the Puget Sound Naval Shipyard, and

2 community colleges. According to the U.S. Census Bureau (2015), the population of Kitsap County is 260,131 with 79.3% of the population being older than 18 years. This population is further broken down with 49% being female and 51% being male. The population breaks down among races with 83% being white, and 3% being black or African American, and 1.8% being American Indian or Alaskan Native, and 5.4% being Asian, the remainder declared a mixture of races. According to Washington State Department of Motor Vehicles (2015), there are 179,977 passenger vehicles registered in Kitsap County in 2015; vehicles in this study will cross all demographics. According to the September 2016 Kitsap county core public health indicators, 16.9% of adults living within the county smoke (KPHD, 2016), no breakdown as to sex or ethnicity is available. However, according to the Washington tobacco facts (2015), 15.0% of the adults in Washington smoke cigarettes. In Washington, the demographics of smokers is 17.9% of males and 14.7% of females smoke (WSDOH, 2015). Smoking percentages by ethnicity in Washington are as shown in Table 1.

Table 1

Kitsap County Population by Ethnicity

Ethnicity	Percentage who smoke
American Indians/Alaskan Natives smoke	36.6
Black/African Americans	16.7
Caucasians	16.6
Hispanic	13.5
Native Hawaiian/other Pacific Islander	24.4
Multiracial	25.4

The breakdown of the population did not affect the research, because all vehicles in the study were smoked in recently. I expected that the vehicles would come from a cross-section of the population.

Recruitment

Recruitment of study participants was completed via fliers placed throughout Bremerton, and local community colleges, eliciting smokers who own vehicles. Vehicles came from within the local area, inside a 25-mile radius, to minimize the impact from differing outside contaminants polluting the interior of the vehicles. I placed recruitment fliers advertising the need for vehicles to be used in a research study in multiple locations in the local community. Individuals who responded were questioned regarding their vehicle; the vehicle was either accepted or excluded. The four exclusion factors were: open air vehicles, vehicles used to carry chemicals within the cabin, vehicles used for agricultural or industrial purposes, owners who did not know when smoking has taken place in the vehicle or smoking habits were unknown. Once a vehicle has been accepted into the study it was placed in a group and the owner will be given a date, place, and time for data collection. I used single stage convenience sampling method for this study. Convenience sampling, while less desirable than other methods, allows recruitment from the local community, including only those respondents who meet the parameters set forth in the study. However, the use of the convenience sampling method allows the sample to include all characteristics of the population recruiting with flyers and posted bills.

Data Collection

Before taking samples of the vehicle placed in the study, the vehicle owner filled out a data sheet, and were provided a copy of the informed consent form for completion. The data sheet questionnaire gathered data regarding smoking habits in the vehicle, length of ownership, when the last tobacco product was smoked in the vehicle, normal window placement and ventilation condition, method of storage, and length of daily driving. Observational data regarding, ambient weather conditions (the wind, relative humidity, rain, temperature) on the day of data collection, type of vehicle, type of interior material, and noticeable burn marks was gathered and documented. The data sheet had a randomly assigned control number that will be used for data collection and analysis.

General sampling

All samples were one cubic meter (m^3) in volume resulting in units of particulates/m^3. Interior samples were taken with the monitor placed on the dash of the vehicle. Two sets of samples were taken in each vehicle. Baseline samples of $PM_{2.5}$ were taken in the cab of the vehicle prior to any intervention, cleaning is performed. For these samples, I followed the algorithm as shown in figure 3. After the initial sample collection, the vehicle was cleaned with the assigned method. After cleaning, the vehicle sat for one hour with the windows and doors closed and the engine and ventilation off. At the end of the one-hour wait, a second set of air samples was obtained using the same algorithm as the initial air sample. Figure 3 shows the flow chart for collection and cleaning of each vehicle.

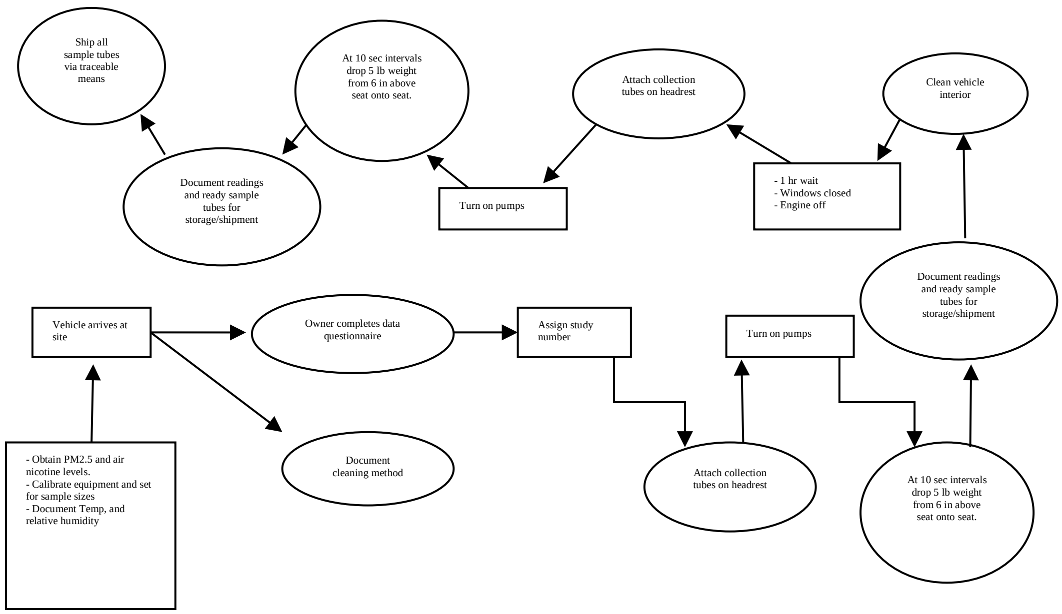

Figure 3. Algorithm for collection and cleaning of vehicles.

Collection technique

Particulate Matter.

PM was measured using the Dusttrak II aerosol monitor; samples will be obtained for 1.0, and 2.5µm. The meter was calibrated, prior to any samples being taken, following the manufactures' recommendations. To ensure consistency in the manner that samples are obtained, an algorithm was developed for the collection of samples. Ambient outside air samples were taken and documented prior to collecting samples within the vehicle. Measurements will be recorded to the 3rd digit.

Nicotine.

Nicotine was measured using gas chromatography using sorbent tube XAD-4, 80/40 as recommended by NIOSH. Sorbent media were obtained from EMSL Analytical Inc., Piscataway, NJ. The XAD-4 media is specific for air nicotine in both the vapor phase and when attached to

PM. NIOSH recommends a flow rate of 0.1 – 1.0 L/min and a total volume between 0.5-600L. A sampling volume of 20L was used for this research. A Buck Libra L-4 rotameter pump with a flow rate of 1 L/min was used to pull the air nicotine samples. The Buck Libra L-4 pump was calibrated in accordance with manufacturers' recommendations prior to, and after daily sample collection to ensure accurate flow rates. Calibration was completed using the Mini-Buck Calibrator utilizing a blank sorbent tube to replicate the actual collection environment, and mimic pressure drop during actual sampling. The same algorithm will be utilized for collection of nicotine as PM. Sorbent tubes were opened just prior to sampling with both ends being broken to allow airflow. Once opened, the tubes were placed in the pump airflow tube and the pump was be turned on to the designated flow rate and volume. At the end of the cycle, the tube was removed, and both ends capped with the provided closures, the tube was labeled, with sample number, and placed in a refrigerated environment and readied for shipment. Samples were shipped via traceable means within 24 hours of collection. Upon receipt of results from EMSL they were entered into the database. EMSL is accredited through the National Voluntary Laboratory Accreditation Program and certified for nicotine testing and processing.

Instrumentation

The algorithm shown in figure 3 was developed for use in the collection of $PM_{2.5}$ and nicotine air samples. The algorithm was beta tested for accuracy and found to accurately replicate conditions in a vehicle while passengers are sitting and moving around within the cabin. The algorithm takes account for a driver and a rear seat passenger.

A data collection tool was developed using questions that were reviewed and determined to collect the data required. Appendix B was developed to gather data regarding the vehicle, its use, normal driving, and smoking habits of the owner. Question 1 determines the volume of the cabin of the vehicle. Questions 2 and 3 determine length of ownership and if the vehicle was purchased used was smoking divulged during the sale. Questions 4, 5 and 6 gather data to determine current smoking habits in the vehicle. Question 6, 7, and 8 determine the mode of operation while smoking to allow for analysis of smoke deposited with differing modes. Questions 9 through 11 determine the type and periodicity of cleaning in the past. Questions 12 and 13 determine how road type affects either PM or nicotine depositing in the vehicle.

Cleaning Methods

There are three usual ways vehicles are cleaned by the owner. Either a carwash coin-operated vacuum is used, a home wet / dry vacuum is used, or a handheld battery-operated vacuum is used. In addition to these, two other options need to be tested. The two methods are passive air renewal and ionic cleaning. Each of these methods has a different ability to clean and/or remove contaminates from the upholstery of a vehicle. For my study I normalized the methods of cleaning to determine if the methods are similar in its abilities. Each of the first three methods were employed for ten minutes of cleaning the interior of the vehicle. Windows in the fourth method were open twenty minutes between samples with no activity in the vehicle. The fifth method the HEPA filtration system operated in the cabin for20-minutes between samples.

Method 1.

Method one is a vacuum at car wash method. This method used a coin-operated vacuum at a local carwash. The car wash has a coin operated J.E. Adams 9235 2-Motor Car Wash Vacuum. This vacuum has two 1.6 Horsepower, 120 Volt motors, a large, stainless steel dome on the top of the unit, and an On/Off toggle switch for easy customer use. This vacuum uses a 2-

inch15 foot hose and has 163 CFM and 193.4 Air Watts. In this method, initial samples were taken using the sampling algorithm, followed by 10 minutes of vacuuming paying attention to the upholstery of the vehicle. After cleaning, the vehicle sat for 1 hour with the windows closed, engine off, and fan off. At the end of the 1-hour period, the second set of samples was obtained using the sampling algorithm.

Method 2.

Method two, wet / dry vacuum. The Rigid wet / dry vacuum used was the 6-gallon 120-volt, 5.8 amp 3.5 Hp model. This model offers 62 CFM and 124 Air Watts using a 1 7/8-inch hose. In this method, initial samples were taken using the sampling algorithm, followed by 10 minutes of vacuuming paying attention to the upholstery of the vehicle. After cleaning, the vehicle sat for 1 hour with the windows closed, engine off, and fan off. At the end of the 1 hour, period the second set of samples were obtained using the sampling algorithm.

Method 3.

Method 3, handheld battery powered vacuum. In this method a Dyson Motorhead V6, was used. The Motorhead offers 100 Air Watts V6 Dyson dc motor, direct drive motor head with 20 minutes of run time per charge. This model was chosen due to it being the most cost efficient and therefore more available to a larger portion of the population. In this method, initial samples were taken using the sampling algorithm, followed by 10 minutes of vacuuming paying attention to the upholstery of the vehicle. After cleaning, the vehicle sat for 1 hour with the windows closed, engine off, and fan off. At the end of the 1 hour, period the second set of samples was obtained using the sampling algorithm.

Method 4.

Method four, open window passive air movement. This method utilized passive air movement to change out the atmosphere in the vehicle. This ensured that any change in $PM_{2.5}$ or air nicotine is not merely a function of time and has no relationship to the cleaning method. In this method, initial samples were obtained using the sampling algorithm. After initial samples were obtained, the vehicle had the windows open for one hour with no activity in the vehicle. After the 1-hour elapsed time, the second set of samples was obtained using the sampling algorithm.

Method 5.

Method 5, HEPA filtration. This method used a HEPA filtration system, the Homdox car air purifier, placed at the level of the arm-rest, front seat for 10 minutes allowing the cabin air to be filtered by the Homdox car air purifier which includes a HEPA filter. This filtration system was developed and used in vehicles; it utilizes a three-level filter and filters out 99.97 percent of all allergens, dust mites pollen, and pet dander, as well as 99 percent of $PM_{2.5}$ in ten minutes. The Homdox air filtration system has a clean air delivery rate of $40m^3$/hr or 23 CFM. The cigarette adaptor, 12 V DC, powers the Homdox car air filtration system. After initial samples were obtained using the same algorithm as the nicotine and PM sampling, the Homdox filtration system was placed in the front seat at the level of the armrest and turned on for 10 minutes with no activity in the vehicle. After the 10-minute Homdox filtration system operation and the 1-hour elapsed time, the second set of samples was obtained using the sampling algorithm. The Homdox car air filter system was cleaned per the manufactures recommendation between vehicles to ensure result outcomes are consistent

Data Analysis

SPSS was used for data analysis. Descriptive analysis included, mean, mode, median, and distribution of each group.

Analysis of Variance – Kruskal-Wallis test analysis was used. Kruskal-Wallis test is used when the data does not meet the assumptions required for ANOVA analysis (Gerstman, 2008). According to Gerstman (2008), there are six assumptions that the data must meet to be able to use ANOVA analysis. The first three are regarding the data and the collection.

- The dependent variables must be either interval or ratio level data.
- The independent variable must consist of more than two categories.
- The observations must be independent.

The data and collection methods used in this research meet these three assumptions allowing ANOVA to be the method of analysis.

Assumptions four through six relate to how the data will be analyzed.

- There cannot be any outliers.
- The dependent variable must follow a normal distribution, the current data does not meet this assumption.
- There must be homogeneity within the variances, the current data does not meet this assumption.

Through an analysis of the data using SPSS I determined the data does not meet assumptions four through six therefore, analysis was conducted using Wilcoxon signed-rank test which does not assume normality in the data, Wilcoxon signed rank testing can be used when this assumption has been violated and the use of the dependent t-test is inappropriate. Wilcoxon-signed rank testing is used to compare two sets of scores that come from the same participants. Wilcoxon signed rank testing will be used to determine any trends in $PM_{2.5}$ and nicotine levels related to interior material or interior volume. Analysis of data to determine correlation between nicotine and $PM_{2.5}$ levels will utilize Spearman's correlation test along with scatter plotting.

Participant and data privacy

No personal identifying information, or data protected by HIPPA was collected or stored during this study. No data that would identify the owner of the vehicle was collected or stored. Data regarding vehicle type, year, and size was collected. Data is stored on a removable hard drive. Each owner was asked to sign a consent form, Appendix A, that will include an indemnity clause to ensuring that neither myself nor Walden University will be held liable for any incidental damage from cleaning. All consent forms are stored both electronically and in hard copy for the required period and then will be destroyed. All participants have been given a copy of the abstract to read to understand the research.

Summary and Transition

In chapter 3 I discussed the methodologies related to the study. Chapter 3 included a discussed related to the purpose of the study, study design, population and sample size, the study setting, recruitment and data collection methods general sampling methods, instrumentation, cleaning methods with an overview of data analysis and participant and data privacy. In chapter 4 I will present the results of the research. I also review data analysis in Chapter 4 and discuss the results of analysis related to each research question. I discuss my interpretation of the findings, limitations and implications of the study, recommendations for future research and my conclusion in chapter 5.

Chapter 4: Results

Introduction

My purpose in this study was to examine how commonly used cleaning methods affect residual ETS levels in the interior of vehicles as measured by $PM_{2.5}$ and air nicotine levels. To achieve this goal, I formulated three research questions. The first research question investigates whether the interior air quality of a vehicle can be improved through cleaning. The null hypothesis for this question was that there would be no significant difference in the $PM_{2.5}$ levels before and after cleaning. The second research question focused on determining how residual $PM_{2.5}$ and air nicotine levels were affected by different cleaning methods. The null hypothesis for this research question stated that there would be no significant differences in the reduction in $PM_{2.5}$ and air nicotine levels between groups. The third research question determined whether $PM_{2.5}$ is an adequate representation of air nicotine levels within the micro-climate of a vehicle cabin. The third null hypothesis stated that no correlation existed between $PM_{2.5}$ and air nicotine levels. This chapter contains a summary of the data collection process and the results of the data analysis procedures.

Data Collection

I conducted this quantitative, causal comparative study between September 2017 and January 2018. Data were collected from 50 vehicles recruited from the local area. I used a combined convenience and purposeful sampling strategy to collect data from vehicles that met the inclusion criteria and were available on testing dates. Data collection included airborne nicotine samples and airborne PM at 2.5microns, as well as survey questionnaire regarding the owners' smoking habits, driving habits and cleaning habits related to the vehicle. Data was collected before and after a variety of cleaning procedures. A Buck Libra L-4 personal air sampling pump was used to measure Air nicotine levels fitted with a flow regulator attached, using sorbent tube XAD-4, 80/40. EMSL calibrated the pump by prior to use, and I verified volume accuracy prior to each day of sampling. PM was measured using an Aero Trak handheld airborne particulate counter calibrated to 2.5 microns.

Descriptive Statistics: Study Participants

Of an initial sample of 95 vehicles, 35 were disqualified for not meeting the inclusion criteria for the study, as outlined in chapter 3. From the remaining 60 accepted the first 50 vehicles were finally accepted into the study, which was 52.6% of the initial sample. These 50 vehicles were placed into five cohorts of 10 vehicles each, while the remaining 10 were placed in reserve in case a participant failed to show; I needed to use three of these vehicles.

Two types of descriptive statistics analysis were conducted. For the categorical variables, frequency statistics were derived, the results of which are shown below in Table 2. The majority of the vehicles had cloth interiors (27 of 50, i.e., 54%), and have been smoked in for 1 to 5 years (32 of 50, i.e., 64%). Most were purchased used (46 of 50, i.e., 92%). Of the 50 cars, the majority were smoked in by only one to two people (39 of 50, i.e., 78%) and were smoked in daily (42 of 50, i.e., 84%). Most of the respondents reported that when the car was smoked in, the windows were half-open (25 of 50, i.e., 50%). The majority of the vehicles were cleaned on a weekly basis (26 of 50, i.e., 52%), and were last cleaned within the last 7 to 14 days (25 of 50, i.e., 50%). The vehicles were usually cleaned either by home vacuum (24 of 50, i.e., 48%) or using a professional vacuum (23 of 50, i.e., 46%). The majority of the vehicles were housed in an urban area, but not garaged (19 of 50, i.e., 38%).

Table 2

Results of Frequency Analysis

	n	%
Interior type		
Leather	7	14.0
Cloth	27	54.0
Faux leather	16	32.0
Length of ownership		
Less than 1 year	9	18.0
1 year to 5 years	32	64.0
More than 5 years	8	16.0
No response	1	2.0
Purchase condition		
New	4	8.0
Used	46	92.0
How many people regularly smoke		
1 to 2	39	78.0
2 to 3	6	12.0
3 to 4	2	4.0
More than 4	3	6.0
How often passengers smoke in vehicle		
Daily	42	84.0
Few days a week	5	10.0
Weekly	1	2.0
Less than weekly	2	4.0
Position of windows when smoking takes place		
Open	16	32.0
Half-open	25	50.0
Closed	9	18.0
How often the vehicle is cleaned		
Daily	4	8.0
Weekly	26	52.0
Monthly	15	30.0
Less than monthly	5	10.0
What is normally used to clean the vehicle		
Home vacuum	24	48.0
Professional vacuum	23	46.0
Professional service	3	6.0
When the vehicle was last cleaned		
Last 3 days	3	6.0
3 to 7 days	8	16.0

7 to 14 days	25	50.0
14 to 21 days	7	14.0
No response	7	14.0
Where the vehicle is housed		
Urban, garaged	13	26.0
Urban, not garaged	19	38.0
Rural, garaged	13	26.0
Rural, not garaged	5	10.0

I also calculated measures of central tendency for the study variables. As shown below in Table 3, both the measurements of air nicotine and $PM_{2.5}$ decreased from the initial measurement to the final measurement. Average air nicotine decreased from 62.42 µg/m³ (*SD* = 8.81) during the initial measurement to 59.66 µg/m³ (*SD* = 8.15) during the final measurement. Likewise, the average $PM_{2.5}$ particulate count decreased from 1,838.56 particles (*SD* = 1211.66) during the initial measurement to 1,582.90 particles (*SD* = 870.36) during the final measurement. For the 50 cars, the average change in nicotine levels was measured to be M = 2.76 µg/m³ (*SD* = 1.64), while the average change in $PM_{2.5}$ was measured to be M = 255.66 Particles (*SD* = 411.82).

Table 3

Descriptive Statistics

	Nicotine (µg/m³)		$PM_{2.5}$ (particles)		Change in nicotine (µg/m³)	Change in $PM_{2.5}$ (particles)
	Initial	Final	Initial	Final		
Mean	62.42	59.66	1838.56	1582.90	-2.76 (4.42%)	-255.66 (13.9%)
SD	8.81	8.15	1211.66	870.36	1.64	411.82
Minimum	51.00	50.00	659.00	523.00	0.00	-9.00
Maximum	85.00	82.00	6155.00	4292.00	-6.00	-1976.00

As part of the preliminary statistics analysis, the data were also tested for the assumption of normality required for the inferential tests that will be conducted. As shown below in Table 4, the significance values of the Shapiro-Wilk test for both the change in nicotine and the change in

PM are less than p = .05. This indicates that the null hypothesis, which states that the data is normally distributed, is rejected. These results show that the data set significantly differs from a normal distribution and that the assumption of normality required for a parametric test was not met. Hence, the non-parametric equivalent of the inferential tests will be conducted.

Table 4

Results of Normality Testing

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df[b]	Sig[c].	Statistic	df[b]	Sig[c].
Change in nicotine	.122	50	.062	.947	50	.025
Change in PM	.366	50	.000	.532	50	.000

a. Lilliefors significance correction
b. Degrees of freedom
c. Significance

Results

Research Question 1.

The first research question of the study is focused on determining whether the interior air quality of a vehicle can be improved through cleaning. To address this research question, a Wilcoxon signed ranks test was conducted as a non-parametric equivalent to the paired samples t-test. In the Wilcoxon signed ranks test, the initial and final measurements of the air nicotine levels and $PM_{2.5}$ levels were compared. The results of the test, as shown in Table 5 below, indicate that there is a statistically significant decrease in both air nicotine ($Z = -6.154$, $p < .001$) and $PM_{2.5}$ levels ($Z = -5.934$, $p < .001$) after cleaning. Based on these results, the first null hypothesis is rejected.

Table 5.

Results of Wilcoxon Signed Ranks Test

	PM $_{2.5}$ Final - Initial Level (particles)	Nicotine Final - Initial Level (μg/m³)
Z[a]	-6.154[b]	-5.934[b]
Asymp. Sig. (2-tailed)	.000	.000

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.

Research Question 2.

The second research question of the study is focused on determining how residual $PM_{2.5}$ and air nicotine levels are affected by different cleaning methods. To address this research question, a Kruskall-Wallis test was conducted as a non-parametric equivalent to the one-way analysis of variance (ANOVA). In the Kruskall-Wallis test, the average change in $PM_{2.5}$ and air nicotine levels were compared to determine if the is a statistically significant difference across groups. The results of the Kruskall-Wallis test, as shown in Table 6 below, indicate that the difference in the average change in nicotine and $PM_{2.5}$ levels do not significantly differ across groups. Based on these results, the second null hypothesis is accepted.

Table 6.

Results of Kruskall-Wallis Test

	Change in nicotine levels (μg/m³)	Change in PM (particles)
Chi-Square[ab]	6.014	3.024
df	4	4
Asymp. Sig.	.198	.554

a. Kruskal Wallis Test
b. Grouping Variable: Cleaning Method

Research Question 3

The third research question of the study is focused on determining whether $PM_{2.5}$ is an adequate representation of air nicotine levels. To address this research question, a Spearman's correlation test was conducted as a non-parametric equivalent to the Pearson's correlation test. The test used data on the initial and final measurements of both $PM_{2.5}$ and air nicotine levels. The results of the test, as shown below in Table 7, indicate that there is no statistically significant association between $PM_{2.5}$ and nicotine levels. The r-value represents the correlation between two variables. The positive or negative sign indicates the nature of the relationship between the variables if it's direct or inverse. The *r*-value indicates the strength of the relationship between the variables. The r-value below 0.3 (+/-) indicates a weak relationship between nicotine and PM. The p-value indicates if the relationship is statistically significant. A cut-off value is p = .05 is used to determine statistical significance,

The results are shown graphically in Figure 4, as a scatter plot with a fit line. In line with the negative r-values of the correlation analysis, the line slopes from left to right, indicating an inverse relationship between the variables. As seen in the R-squared value in the scatter plot, the relationship between the variables is less than r = 0.3, which indicates a weak relationship between the variables. Likewise, the slope of the fit line confirms the weak relationship between the two nicotine and $PM_{2.5}$. Based on these results, the third null hypothesis is accepted.

Table 7.

Results of Spearman's Correlation Analysis

	Initial nicotine levels (µg/m³)		Final nicotine levels (µg/m³)	
	r	p	r	p
Initial PM2.5 levels	-.018	.900	-.014	.921
Final PM2.5 levels	-.067	.645	-.063	.664

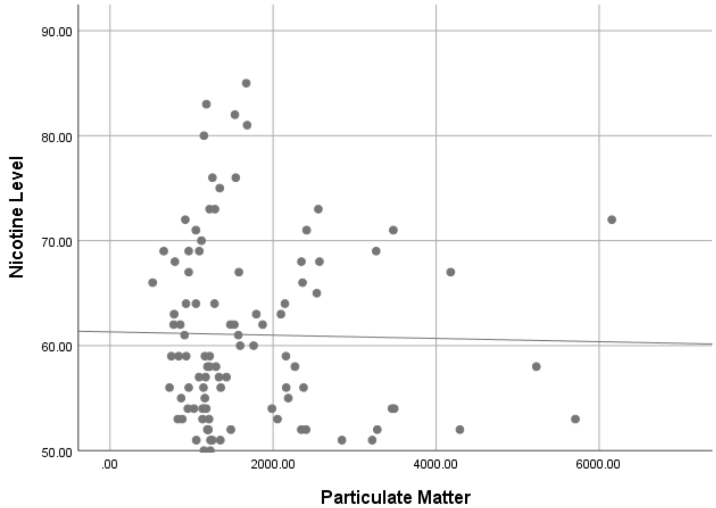

Figure 4. Scatter with Fit Line – Nicotine (μg/m³) and PM2.5 (particles)

Summary

This chapter contained the results of the data analysis procedures conducted in line with the purpose of the study and the associated research questions. The results of the data analysis indicated that based on the results of the Wilcoxon signed ranks test, there was a statistically significant decrease in both the $PM_{2.5}$ and air nicotine levels in the tested cars after cleaning. However, based on the results of the Kruskall-Wallis test, it was also determined that there were no statistically significant differences in the reduction of $PM_{2.5}$ and nicotine levels across the different types of cleaning methods used. Lastly, the results of the Spearman's correlation test indicated that there was no statistically significant correlation between $PM_{2.5}$ measurements and nicotine levels. These results will be discussed in relation to existing literature in the final chapter of this study. The final chapter will also include a discussion of conclusions and recommendations made based on these results. In chapter 5 I discuss my interpretation of the findings, limitations and implications of the study, recommendations for future research and my conclusion.

Chapter 5: Discussion, Conclusions, and Recommendations

Introduction

It has been a serious concern that the occupants of vehicles where smoking has occurred may be chronically exposed to low levels of ETS, which may be through inhalation of re-aerosolized ETS or by absorption through the skin (Fortmann et al., 2010; Matt et al., 2008). Previous studies have linked that the presence of low-level ETS exposure may cause detrimental mental and medical health conditions (Guerin et al., 1992; Yolton et al., 2005). The gap in this study dealt with the effectiveness of common methods used to remove ETS from the cabin of vehicles. It is of paramount importance to ensure that there is a proper way to remove ETS from the interior of vehicles for the benefit of the occupants. My purpose in this study was examine how commonly used cleaning methods affect residual ETS levels in the interior of vehicles as measured by $PM_{2.5}$ and air nicotine levels. In this study, I provide positive social change with respect to determining methods that have significant impact on the reduction of chronic health effects related to exposure to ETS. Positive social influence will be through determining effective methods for cleaning the interior of vehicles that provide significant reduction in ETS exposure. The results are relevant because the results provide beneficial information to the public health community and the general public on methods to reduce ETS exposure.

The first research question investigated whether the interior air quality of a vehicle may be improved through cleaning. The null hypothesis for this question was that there will be no significant difference in the $PM_{2.5}$ levels before and after cleaning. The second research question was focused on determining how residual $PM_{2.5}$ and air nicotine levels were affected by different cleaning methods. The null hypothesis for this research question stated that there will be no significant differences in the reduction in $PM_{2.5}$ and air nicotine levels between groups. The third research question determined whether $PM_{2.5}$ is an adequate representation of air nicotine levels. The third null hypothesis stated that no correlation between $PM_{2.5}$ and air nicotine levels.

The findings of the study indicated that based on the results of the Wilcoxon signed ranks test, there was a statistically significant decrease in both the $PM_{2.5}$ and air nicotine levels in the tested car interiors after the utilization of the cleaning methods. Furthermore, based on the results of the Kruskall-Wallis test used in the data analysis, I determine no statistically significant differences in the reduction of $PM_{2.5}$ and nicotine levels across the different types of cleaning methods used. Based on this, it may be inferred that the different methods of cleaning have no statistical difference in terms of effectiveness in cleaning. Moreover, the results of the Spearman's correlation test indicated that there was no statistically significant correlation between $PM_{2.5}$ measurements and nicotine levels. Thus, it may be inferred that PM are independent of the existence and levels of nicotine in the interiors of the vehicles.

Interpretation of the Findings

The first research question of the study determined whether the interior air quality of a vehicle can be improved through cleaning. To be able to answer this research question, a Wilcoxon signed ranks test was conducted as a nonparametric equivalent to the paired samples t-test. In the Wilcoxon signed-ranks test, compared the initial and final measurements of the air nicotine levels and $PM_{2.5}$ levels. The findings of the test indicated a statistically significant decrease in both air nicotine and $PM_{2.5}$ levels after cleaning of the interiors of the car. This is contrary to the first hypothesis of the study. The first hypothesis for this question was that there would be no significant difference in the $PM_{2.5}$ levels before and after cleaning. Based on these results, the first null hypothesis is rejected.

I studied five methods to clean the interior of the vehicles in this study. The first method was the vacuum at car wash method. The second method was the wet/dry vacuum. The third method was the handheld battery powered vacuum. The fourth method was the open window-passive air method. The fifth method was the HEPA filtration. Based on the findings of the study, it can be inferred that all cleaning methods studied are effective in cleaning the interiors of the car. This is evident in the difference between the $PM_{2.5}$ levels and nicotine levels before and after cleaning. The conceptual framework of this study discussed the concept of primary prevention, which aims to protect healthy people from becoming ill or injured (Gullotta, 1994). Based on the findings of the study, it may be inferred that cleaning the interiors of the car would be helpful to advance and progress in primary prevention. Primary prevention includes certain actions conducted to prevent exposure to, reduce exposure to, or minimize the effects from exposure to harmful substances or environments. It is noteworthy that the cleaning methods used in this research may be used to insure primary prevention is implemented. Primary prevention includes protecting both healthy persons and persons who may have pre-existing conditions from ETS. Providing a healthy environment is one aspect of primary prevention. The findings of the study note that the nicotine levels and $PM_{2.5}$ levels are substantially lessened after using any of the five cleaning methods.

It has been found in the literature of the study that when smoking occurs in vehicles, $PM_{2.5}$ and nicotine levels can reach have been measured as high as 3500ug/m3 (Edwards et al., 2006). This level of PM and nicotine levels are not recommended because of the high risks to health that can be attributed to it. Although these levels are reduced when the windows are open or when the cigarette is held outside the vehicle, $PM_{2.5}$ and nicotine levels remain significantly higher than ambient air (Edwards et al., 2006; Jones, Navas-Acien et al., 2009). The results of the study confirmed this literature. In the study cited, it says that a significant difference exists in the nicotine levels when the windows are open that when they are closed. It is related to the fifth method of passive air and open window method. More so, the hypothesis is affirmed that cleaning the upholstery of a vehicle reduces PM levels.

The second research question of the study was focused to determine how residual $PM_{2.5}$ and air nicotine levels were affected by different cleaning methods. To address this research question, I conducted Kruskall-Wallis test as a nonparametric equivalent to the one-way analysis of variance (ANOVA). In the Kruskall-Wallis test, competed the average change in $PM_{2.5}$ and air nicotine levels to determine whether the is a statistically significant difference across cleaning methods. The results of the Kruskall-Wallis test indicated that the difference in the average change in nicotine and $PM_{2.5}$ levels do not significantly differ across groups. The findings of the study confirmed the second hypothesis. The null hypothesis for this research question states that there will be no significant differences in the reduction in $PM_{2.5}$ and air nicotine levels between groups. Based on these results, the second null hypothesis is accepted. Through this finding, it may be inferred that the different methods are equally effective.

There is no real-time monitoring available for nicotine (Apelberg et al., 2008). Because there is no real-time monitoring for nicotine, it may be argued that the nicotine levels measured were actually not the nicotine levels at the time after the cleaning methods were employed. There are two methods for measuring nicotine in the environment that are accepted as accurate.

Nicotine can be measured with passive monitors, or active monitors (Apelberg et al., 2008). Both methods of detecting the presence of nicotine (measure as nicotine) utilize a medium that absorbs nicotine from the environment and is processed later by a laboratory (Apelberg et al., 2008). Based on the findings of the study, it may be inferred that a device that simultaneously measures real time presence of nicotine and $PM_{2.5}$ might have significantly affected the results and findings of this study. However, given the relatively low volume of air for the nicotine sample, this is unlikely.

The third research question of the study determined whether $PM_{2.5}$ is an adequate representation of air nicotine levels. To answer this research question, I conducted a Spearman's correlation test as a nonparametric equivalent to the Pearson's correlation test. The test used data on the initial and final measurements of both $PM_{2.5}$ and air nicotine levels. The results of the test indicated that no statistically significant association between $PM_{2.5}$ and nicotine levels. The results were graphically shown in the previous chapter a scatter plot with a fit line. In line with the negative r-values of the correlation analysis, the line slopes from left to right indicated an inverse relationship between the variables. As seen in the R-squared value in the scatter plot, the relationship between the variables indicated a weak relationship between the variables. Likewise, the slope of the fit line confirmed the weak relationship between the two variables of nicotine and $PM_{2.5}$. The third null hypothesis states no correlation between $PM_{2.5}$ and air nicotine levels. Based on these results, the third null hypothesis is accepted.

PM is categorized and classified by how far down the respiratory tract they can reach based on its size (Brown et al., 2013). PM smaller in size will have further reach in the respiratory tract than the PM with larger size. Since it was found in this study that there is no correlation between $PM_{2.5}$ and nicotine levels, it may be inferred that nicotine levels are generally not associated with PM in smaller sizes. PM larger than 10μm is considered inhaled particulates and remains in the extrathoracic airways of a human being. This means that larger PM does not pass beyond the larynx (Brown, et al., 2013). Thus, larger PM will not be able to penetrate the lungs and other inner organs of a person. On the other hand, PM smaller than 10μm is considered thoracic, reaching smaller airways. Despite the fact of the far-reaching smaller PMs, it can still be inferred that the presence of smaller PM was found to be not significantly correlated to the presence of nicotine levels.

It has been understood that PM with a diameter of 2.5μm is considered respirable and is carried to the lower portions of the lungs and may cause damage to the respiratory system (Brown et al., 2013; Xing et al., 2016). Despite its capability to penetrate the lungs, the findings of the study found that the presence of smaller PM is not really associated with nicotine levels and ETS in the interiors of the vehicles examined. $PM_{2.5}$ has a smaller diameter but it is known to have a larger surface area and is capable of carrying other toxic chemicals (Xing et al., 2016). Based on the findings of the study, there was no significant finding that the presence of $PM_{2.5}$ carrying toxic chemicals is associated with the availability of ETS and nicotine inside the vehicles, after smoking. Research has validated that $PM_{2.5}$ is uniquely representative of ETS in the environment (Apelberg at al., 2008; Guerin et al., 1992; Offermann et al., 2002). Despite this finding in current literature, the status of the presence of $PM_{2.5}$ and nicotine levels in the interior vehicles in this study does not support the literature that $PM_{2.5}$ is uniquely representative of ETS in the environment. However, it bears noting that the findings of the study do not also reject the fact that $PM_{2.5}$ specifically represents ETS since the sample only involved certain vehicles and the interiors after cleaning. It may be noted that the presence of $PM_{2.5}$ may be more apparent before the cleaning methods were employed.

Limitations of the Study

There were several limitations to this study including the population size used for the sample and weather patterns during the research. It bears noting that a small and limited population has an impact on the generalizability of the results of the study. This study was also limited to investigate the association between ETS levels and removal methods available at the time of the study. Thus, the results and findings of the study were likewise limited by the data collected from the specific vehicles examined by the researcher using the device employed in this study. It also bears noting that the study was not able to focus on all the vehicle types and the interior of the vehicles studied in this research was likewise limited by the type of vehicles.

Another limitation in this study can be attributed to the patterns of the weather when the study was conducted. It is noteworthy that changes in the weather and climate may significantly impact the results of the cleaning methods and also the absorption of ETS levels in the interiors of the vehicles. The results of the study were likewise limited by certain assumptions that had to be made in the course of the study. The study assumed that all the tobacco smoked in the sample vehicles produced comparable PM. Another limitation of the study was with regard to the measurement of only a specific size of PM and nicotine levels in ETS. This may pose a limitation because the presence of other sizes of PM was not analyzed in this study. Thus, the effectiveness of the cleaning methods was not analyzed in an in-depth level as to determine the sizes of PM and the presence of other chemicals, other than nicotine.

Recommendations

Future research may focus on a single method of cleaning or the effects of the cleaning methods to different interiors of a vehicle. To give an example, the interiors of the vehicles may be of different sizes, shapes and materials. In this manner, the effect of a single cleaning method will be analyzed in terms of its effectiveness on certain materials of the interiors. Further, it is also recommended for future research to conduct the study in a different climate or weather. It was raised as one of the limitations of the study that the weather patterns may have affected the results and findings of the study. Thus, future research may also focus on the same research method and sample but on a different season or climate. Future studies may also focus on measuring not just the presence of a specific size of PM and nicotine levels, but also the other sizes of PM. Other chemicals and toxic materials may also be measured before and after the utilization of cleaning methods. In this instance, future research may also be more focused in terms of determining which kind of cleaning method is more effective in eliminating certain types of toxic materials.

The current study used the quantitative method with quasi-experimental and case-control approach. It bears noting that the research method used may also be changed for future studies. To give an example, future research may use qualitative method or mixed methods. The lived experiences and perceptions of the owners and/or occupants of the vehicles may be studied based on their opinion after specific cleaning methods are used on the vehicle samples. Thus, the effectiveness of the cleaning methods may be measured based on the lived experiences and observations of the participants. In this way, the findings of the study will also factor in the actual experiences of the owners and occupants of the vehicles.

Implications

Positive Social Change: The results of the study have a positive social change in respect to a significant impact on the reduction of chronic health effects if effective methods in cleaning the interior of vehicles are recognized. The results of the study will significantly impact the community because ETS-free environments will contribute in the improvement of general health and reduction of health costs. Overall, productivity will be increased, and the quality of life will improve. The social implications of the study also include the fact that the occupant of a vehicle will be stopped from being exposed to ETS. Further, the burden of medical costs may also be significantly reduced. There will be an apparent positive social change when the chronic low-level exposure to ETS is reduced. The findings of the study will likewise inform the society and educate people on the best way to perform the removal of ETS from vehicles. It can be said that exposure to ETS poses a serious public concern that has impacted several sectors and stakeholders in public places. Thus, the study has significant impact to the welfare of the community because the results will help lessen the exposure of vehicle occupants to ETS.

In terms of research, the findings of the study will help other researchers in focusing on other matters as fields of study. To give an example, future research may be specifically focused on the level of ETS of certain types of vehicle interiors and determine which method of removal of ETS works best for certain vehicle interiors. It bears noting that different methods may have different levels of effectiveness when applied to certain types of vehicles. The findings of the study may also have impact on the research and development field. The researchers involved in designing different equipment and methods may be able to formulate better methods of removal of ETS in car interiors, depending on the findings of the study.

Conclusion

There is a growing concern about the exposure of the occupants of vehicles to low levels of ETS when the interior of vehicles has been exposed to high level of nicotine. It is important to know certain cleaning methods that are effective in ensuring that the presence of PM and nicotine is low to benefit the health of the occupants and owners of the vehicles. The purpose of this study was to conduct an examination to determine how commonly used cleaning methods affect residual ETS levels in the interior of vehicles as measured by $PM_{2.5}$ and air nicotine levels. The research used five different cleaning methods on the vehicles. The findings of the study found that there was significant difference in the $PM_{2.5}$ levels before and after cleaning. The second finding found that there were no significant differences in the reduction in $PM_{2.5}$ and air nicotine levels between groups. The findings confirmed that there was no correlation between $PM_{2.5}$ and air nicotine levels. The findings of the study have impact on the development of research on effective cleaning methods to be used. Further, the findings are also helpful in ensuring that the community have informed and sufficient choices in cleaning the interior of the vehicles for the betterment of health and welfare.

References

American Society for Testing and Materials (ASTM), Active Standard ASTM D5075. (2012 e1) Standard tests methods for nicotine and 3-ethenylpyridine in indoor air. Retrieved from http://www.astm.org/standards/D5075.htm

Apelberg, B. J., Hepp, L. M., Avila-Tang, E., Gundel, L., Hammond, S. K., Hovell, M. F., Breysse, P. N. (2013). Environmental monitoring of secondhand smoke exposure. *Tobacco Control*, *22*(3), 147-155. doi:10.1136/tobaccocontrol-2011-050301

Borio, G. (2011). The tobacco timeline. Retrieved from http://www.tobacco.org/resources/history/Tobacco_Historynotes.html

Brown, J. S., Gordon, T., Price, O., & Asgarian B. (2013) Thoracic and respirable particle definitions for human health risk assessment. *Particle and Fibre Toxicology, 10*(12), doi.org/10.1186/1743-8977-10-12.

Bush, D., & Goniewicz, M. L., (2015). A pilot study on nicotine residuals in houses of electronic cigarette users, tobacco smokers, and non-smokers of nicotine containing products. *International Journal of Drug Policy*, *26*(6), 609-611. doi: 10.1016/j.drugpo.201503.003

Castelao, J., Yuan, P., Tannenbaum, S., Gago-Dominguez. M., Crowder, S., Ross, R., &Yu, M., (2001). Gender- and Smoking related Bladder Cancer Risk. Journal of the National Cancer Institute, 93(7). 538-545. doi.org/10.1093/jnci/93.7.538

Centers for Disease Control and Prevention. (2008). Smoking – Attributable mortality, years of potential life lost, and productivity losses --- United States, 2000 - 2004. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5745a3.htm

Comhair, S. A., Gaston, B. M., Ricci, K. S., Hammel, J., Teague, G., Meyers, D., . Erzurum, S. C. (2011). Detrimental effects of environmental tobacco smoke in relation to asthma severity. *PloS One*, *6*(5): e18574. doi:10.1371/journal.pone.0018574

Creswell, J. W. (2009). Research design, qualitative, quantitative, and mixed methods approaches. Thousand Oaks, CA: Sage Publishing.

Creswell, J. W. (2013). *Qualitative inquiry & research design: Choosing among five approaches*. Thousand Oaks, CA. Sage Publication.

Crosby, R. A., DiClemente, R. J., & Salazar, L. F, (2006). *Research methods in health promotions*. San Francisco, CA. Josey-Bass.

Curto, A., Martiniez-Sanchez, J. M., & Fernandez, E. (2011). Tobacco consumption and second-hand smoke exposure in vehicles: A cross-sectional study. *British Medical Journal Open*, *1*, e000418. doi:10.1136/bmjopen-2011-000418

Davis V. Honeywell International Inc., *Volume F Supp. Page (Cal, 2016)*

Dockery, D. W. (2009). Health effects of particulate air pollution. *Annuals of Epidemiology*, *19*, 257-263. doi:10.1016/j.annepidem.2009.01.018

Donovan, D., McDowell, I., & Hunter, D. (Eds.). (2008). Primer on population health. Retrieved from http://phprimer.afmc.ca/inner/primer_contents

Dreyfuss, J. H. (2010). Third-hand smoke identified as potent, enduring carcinogen. *Cancer Journal for Clinicians*, *60*(4), 203. doi.org/10.3322/caac.20079

Edwards, R., Wilson, N., & Pierse, N. (2006). Highly hazardous air quality associated with smoking in cars: New Zealand pilot study. *The New Zealand Medical Journal*, *119*(1244), 103-106. Retrieved from http://www.nzma.org.nz/journal/119-1244/2294/

Farkas, A. J., Gilpin, E. A., Distefan, J. A., & Pierce, J. P. (1999). The effects of household and workplace smoking restrictions on quitting behaviors. *Tobacco Control*, *8*, 261-265. doi:10.1136/tc8.3.264

Feroruk, M. J., & Kerger, B. D. (2003). Measurement of volatile organic compounds inside automobiles. *Journal of Exposure Analysis and Environmental Epidemiology, 13*, 31-41. doi:10.1038/sj.jea.7500250

Floyd, D. L., Prentice-Dunn, S., & Rogers, R. W. (2000). A meta-analysis of research on the protection motivation theory. *Journal of Applied Social Psychology*, *30*(2), 407-409. doi.org/10.1111/j.1559-1816.2000.tb02323.x

Fortmann, A. L., Romero, R. A., Sklar, M., Pham, V., Zakarian, J., Quintana, P. J., Chatfield, D., & Matt, G. E. (2010). Residual tobacco smoke in used cars: Futile efforts and persistent pollutants. *Nicotine and Tobacco Research*, *12*(10), 1029-1036 doi:10.1093/ntr/ntq144

Gerstman, B. B. (2008). *Basic biostatistics: Statistics for public health practice*. Boston, MA: Jones and Bartlett.

Goodman, J. (2005). *Tobacco history: The cultures of dependence*. New York, NY: Routledge.

Grob, G. (2011). *Major tobacco-related events in the United States*. Princeton, NJ: Robert Wood Johnson Foundation.

Guerin, M. R., Jenkins, R. A., & Tomkins, B. A. (1992). *The chemistry of environmental tobacco smoke: Composition and measurement*. Chelsea, MI. Lewis Publishers, Inc.

Gullotta, T. P. (1994). The what, who, why, where, when, and how of primary prevention. *The Journal of Primary Prevention*, *15*(1), 4-15. doi.org/10.1007/BF02196343

Hammer, T. R., Fischer, K., Mueller, M, & Hoefer, D. (2011). Effects of cigarette smoke residues from textiles on fibroblasts, neurocytes and zebrafish embryos and nicotine permeability through human skin. *International Journal of Hygiene and Environmental Health*, *214*, 384-391. doi.org/10.1016/j.ijheh.2011.04.007.

He, B., Zhao, S., & Peng, Z. (2013). Effects of cigarette smoking on HDL quantity and function: Implications for Atherosclerosis. *Journal of Cellular Biochemistry*, *114*(11), 2431-2436. doi:10.1002/jcb.24581

Invernizzi, G., Ruprecht, A., Rossetti, E., Sasco, A., Nardini, S., & Boffi, R. (2014). Particulate matter from tobacco versus diesel car exhaust: an educational perspective. *Tobacco Control*, *13*, 219-221. doi: 10.1136/tc.2003.005975

Jaakkola, M. S., & Jaakola, J. J. (1997) Assessment of exposure to environmental tobacco smoke. *European Respiratory Journal*, *10*, 2384-2397. doi:10.1183/09031936.97.10102384

Jones, M. R., Navas-Acien, A., Yuan, J., & Breysse, P. N. (2009). Second-hand tobacco smoke concentrations in motor vehicles. *Tobacco Control*, *000*(1-6), doi:10.1136/tc.2009.029942

Ke-wei, Y., Yun-shan, G., Bin, H., Zhan-wu, N., Shou-tang, Z., Yan-ni, Z., & Peng, X. (2007). Measurement of in-vehicle volatile organic compounds under static conditions. *Journal of Environmental Sciences*, *19*, 1208-1213. doi 10.1016/S1001-0742(07)60197-1

Kitsap Public Health District [KPHD](2016). Kitsap County Core public health indicators with comparisons to Washington State. Retrieved from kitsappublichealth.org

Kramer, U., Lemmen, C. H., Behrendt, H, Link, E., Schafer, T., Gostomzyk, J., Scherer, G., & Ring, J. (2004). The effects of environmental smoke on eczema and allergic sensitization in children. *British Journal of Dermatology*: *150*(1), 111-118. doi.org/10.1111/j.1365-2133.2004.05710.x

Kum-Nji, P., Meloy, L., & Herrod, H. G. (2006). Environmental tobacco smoke exposure: prevalence and mechanisms of causation of infections in children. *Pediatrics: 117*(5) 1745-1754. doi:10.1542/peds,2005-1886

Lannerö, E., Wickman, M., van Hage, M., Bergström, A., Pershagen, G., & Nordvall, L. (2008). Exposure to environmental tobacco smoke and sensitization in children. *Thorax: British Medical Journal*, *63*,172-176. doi:10.1136/thx.2007.079053

Lenton, S., & Single, W. (1998). The definition of harm reduction. *Drug and Alcohol Review 17*(2), 213-219. doi:10.1080/09595239800187011

MacKay, J., & Eriksen, M. (2002). The Tobacco Atlas. The World Health Organization, Genevia, Switzerland.

Mannio, D. M., Moorman, J. E., Kingsley, B., Rose D., & Repace, J. (2001). Health effects related to environmental tobacco smoke exposure in children in the United States. *Archives of Pediatric and Adolescent Medicine*. Jan 2001: 155(1) Retrieved from http://archpedi.ama-assn.org/cgi/content/abstract/155/1/36

Matt, G. E., Quintana, P. J. E., Zakarain, J. M., Fortman, A. L., Chatfield, D. A., Hoh, E., Uribe, A. M., & Hovell, M.F. (2008). Residual tobacco smoke pollution in used cars for sale: Air, dust, and surfaces. *Nicotine & Tobacco Research*:*10*(9), 1467–1475. doi:10.1080/14622200802279898

Matt, G. E., Quintana, P. J. E., Zakarain, J. M., Fortman, A. L., Chatfield, D. A., Hoh, E., Uribe, A. M., & Hovell, M.F. (2011). When smoker move out and nonsmokers move in: Residential thirdhand smoke pollution exposure. *Tobacco Control*: *20*(1). doi: 10.1136/tc320103037382

Matt, G. E. (2013). Thirdhand tobacco smoke: Emerging evidence and arguments for a multidisciplinary research agenda. *Environmental Health Perspectives*, *119*, 1218-1226. doi:10.1289/ehp.1103500

McCarville, M., Song, M., Oh, E., Weiss, K., & Gupta, R. (2013) Environmental tobacco smoke and asthma exacerbations and severity: The difference between measured and reported exposure. *Archives of Disease in childhood*. *98*, 510-514. doi:10.1136/archdischild-2012-303109

Mitchell, C. S., Zhang, J., Sigsgaard, T., Jantunen, M., Lioy, P. J., Samson, R., & Karol, M. H. (2007). Current state of science: Health effects of indoor environmental quality. *Environmental Health Perspectives*, *116*(6), 958–964. doi: 10.1289/ehp.8987

Molhave, L., (2003) Organic compounds as indicators of pollution. *Indoor Air 13*(Supp; 6), 12-19. doi.org/10.1034/j.1600-0668.13.s.6.2.x

Mueller, D., Uibel, S., Braun, M., Kingelhoefer, D., Takemura, M., & Groneberg, D. A. (2011). Tobacco smoke particles and indoor air quality (TOPIQ) - the protocol of a new study. *Journal of Occupational Medicine and Toxicology*, *6*(35) doi.org/10.1186/s12995-015-0047-8

National Cancer Institute (NCI 1999). Health effects of exposure to environmental tobacco smoke. *Smoking and Tobacco Control Monograph* 10. Retrieved from http://cancercontrol.cancer.gov/brp/tcrb/monographs/10/index.html

National Library of Medicine (NLM 2015) Nicotine Drug Record. Retrieved from http://livertox.nih.gov/Nicotine.htm

Oberg, M., Jaakkola, M. S., Woodward, A., Peruga, A., & Pruss-Ustun, A. (2011). Worldwide burden of disease from exposure to second-hand smoke: A retrospective analysis of data from 192 countries. *The Lancet, 377*, 139-146. doi:10.1016/S0140-6736(10)61388-8

Offermann, F. J., Colfer, R., Radzinski, P., & Robertson, J. (2002). Exposure to environmental tobacco smoke in an automobile. *Proc. Indoor Air*, 506-511. Retrieved from https://www.researchgate.net/profile/

O'Neill, M. S., Jerrett, M., Kawachi, I., Levy, J. I., Cohen, A. J., Gouveia, N., Wilkinson, P., Fletcher, T., Cifuentes, L., & Schwartz, J. (2003). Health wealth and air pollution: advancing theories and methods. *Environmental Health Perspectives*, *111*(16), 1861-1870. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1241758/pdf/ehp0111-001861.pdf

Patton, M, Q. (2002). *Qualitative Research & Evaluation Methods*. Thousand Oaks, CA, Sage Publication.

Pope, C. A., Eatough, D. J., Gold, D. R., Pang, Y., Nielsen, K. R., Nath, P., Verrier, R. L., & Kanner, R. E. (2001). Acute exposure to environmental tobacco smoke and heart rate Variability. *Environmental Health Perspectives*, *109*(7), 711-719. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1240375/

Quintana, P. J. E., Matt, G. E., Chatfield, D. A., Zakarain, J. M., Fortman, A. L., & Hoh, E. (2013). Wipe sampling for nicotine as a marker of thirdhand tobacco smoke contamination on surfaces in homes, cars, and hotels. *Nicotine & Tobacco Research; 15*(9), 1555-1563. doi: 10.1093/ntr/ntt014

Rees, V. W., & Connolly, G. N. (2006). Measuring air quality to protect children from secondhand smoke in cars. *American Journal of Preventive Medicine*, *31* (5). 363-368. doi:10.1016/j.amepre.2006.07.021

Savage, M. A., Kawanabe, I. T., Mejeur, J., Goehring, J. B., & Reed, J. B., (2002, December). Protecting Children A guide to child traffic safety laws. National Conference of State Legislatures

Schuck, K., Kleinjan, M., Otten, R., Engels, R., & DiFranza, J. R. (2013) Responses to environmental smoking in never-smoking children: can symptoms of nicotine addiction develop in response to environmental tobacco smoke exposure? *Journal of Psychopharmacology*, *27*(6) 533-540. doi: 10.1177/0269881112466184

Sendzik, T., Fong, G. T., Travers, M. J., & Hyland, A. (2009). An experimental investigation of tobacco smoke pollution in cars. *Nicotine & Tobacco Research*; 11(6), 627-634. doi:10.1093/ntr/ntp019

Srinivassan, S., O'Fallan, L. R., & Dearry, A. (2003). Creating healthy communities, healthy homes, healthy people: Initiating a research agenda on the built Environment and Public Health. *American Journal of Public Health*, *93*(9), 1446-1450. doi:10.2105/AJPH.93.9.1446

Stratton, K. Shetty, P., & Wallace, R., & Bondurant, S., (2001). Clearing the smoke: The science base for tobacco harm reduction. *Tobacco Control, 10*, 189-195. doi:10.1136/tc.10.2.189

Stimson, G. (1998). Harm reduction in action: putting theory into practice. *International Journal of Drug Policy* (9) 401-409

United States Census Bureau (2015). Quick Facts, Kitsap County Washington. Retrieved from https://www.census.gov/quickfacts/table/PST045215/53035

United States Department of Labor, Occupational Safety & Health Administration (OSHA, 2016). Nicotine, (29 CFR 1910.1000). Retrieved from https://www.osha.gov/dts/chemicalsampling/data/CH_256500.html

United States Department of Health and Human Services (HHS, 2006). The Health Consequences of Involuntary Exposure to Tobacco Smoke: A Report of the Surgeon General. Retrieved from http://www.surgeongeneral.gov/library/reports/second-handsmoke/fullreport.pdf

United States Environmental Protection Agency (EPA, 2013). Pollution Prevention and Toxins. Retrieved from http://www.epa.gov/oppt/

United States Environmental Protection Agency (EPA, 2015). Particulate Matter (PM) Basic Information. Retrieved from http://www3.epa.gov/airquality/particlepollution/basic.html

Wagenaar, A. C., & Webster,D. W., (1986). Preventing injuries to children through compulsory automobile safety seat use. Pediatrics, 18(4). Retrieved from http://pediatrics.aappublications.org/content/78/4/662.short

Wang, S. S., Shi, Q. M., Li, W. Q., Niu, J, F., Li, C. J., & Zhang, F. S. (2008). Nicotine concentrations in leaves of Flue-cured Tobacco Plants as Affected by Removal of the

Shoot Apex and Lateral Buds. *Journal of Integrative Plant Biology*, 50(8), 958-964. doi:10.1111/j.1744-7909.2008.00684.x

Wang, B., Ho, S. S., Ho, K. F., Huang, Y., Chan, C. S., Feng, N. S., & Ip, S. H. (2012). An Environmental Chamber Study of the Characteristics of Air Pollutants Released from Environmental Tobacco Smoke. *Aerosol and Air Quality Research*, 12, 1269-1281. doi: 10.4209/aaqr.2011.11.0221

Washington State Department of Health [WSDOH](2015). Tobacco facts – Washington State 2015 update. Retrieved from www.doh.wa.gov/DataandStatisticalReports/HealthBehaviors/Tobacco

Washington State Department of Licensing (WDOL), Vehicle and Vessel fee distribution reports (2015). Retrieved from https://fortress.wa.gov/dol/vsd/vsdFeeDistribution/DisplayReport.aspx?rpt=2015C00-63.csv&countBit=1

Xing, Y., Xu, Y., Shi, M., & L. Y. (2016). The impact of PM2.5 on the human respiratory system. *Journal of Thoracic Disease*; 8(1), E69-74. doi:10.3978/j.issn.2072-1439.2016.01.19

Xu, M., Nemaollahi, M., Sextro, R. G., Gadgil, A. J., & Nazaroff, w. W. (1994). Deposition of Tobacco Smoke in a Low Ventilation Room, *Aerosol Science and Technology*; 20(2), 194-206. doi.org/10.1080/02786829408959676

Yolton, K., Dietrich, K., Auinger, P., Lanphear, B. P., & Hornung, R. (2005). Exposure to Environmental Tobacco Smoke and Cognitive Abilities among U. S. Children and Adolescents. *Environmental Health Perspectives*; 113(1), 98-103. doi:10.1289/ehp.7210

Zeller, M., Hatsukami, D. (2009). The Styrategic Dialogue on Tobacco Harm Reduction: a vision and blueprint for action in the US. *Tobacco control*, Published Online First: 24 February 2009. doi: 10.1136/tc.2008.027318

Appendix A

Informed Consent Form

This informed consent form proves your understanding and agreement to the following:

1. I agree to participate in the research project as explained by Brian Nielson.

2. This participation agreement is of my own free will.

3. I have been given information regarding the aim of this research and have no questions.

4. I am aware of the research to be conducted on __________[dd/mm/yy] for the purpose of __________________________________.

5. I understand that Brian Nielson a PHD candidate at Walden University, who is also the primary investigator for the project, will conduct the research.

6. I am aware that I will not derive any gain [monetary or otherwise] from this project or research.

7. I am aware of the procedure that will be conducted on/in my vehicle by Brian Neilson, and the data that will be collected.

8. I have the ability to withdraw from the research at any time before or during the data collection process.

9. I will not hold Brian Neilson or Walden University liable for any damage to my vehicle that may result from the research or data collection performed.

Signature of participant: ________________________ Date: ___________

Signature of Investigator: ________________________ Date: ___________

Appendix B: Questionnaire

1) Make of vehicle: _____________ Model of Vehicle: __________________

2) How long have you owned this vehicle?
   a. less than 1 year
   b. one to 5 years
   c. greater than 5 years

3) Did you purchase this vehicle:
   a. New
   b. Used
      i. Do you know if the previous owner smoked in the vehicle
         1. No
         2. Yes

4) Do you allow smoking in the vehicle
   a. No
   b. Yes
      i. How many people regularly smoke in the vehicle:
         1. 1-2
         2. 2-3
         3. 3-4
         4. More than 4

5) How often do you or passengers smoke in the vehicle:
   a. Daily
   b. A few days per week
   c. Weekly
   d. Less often than weekly

6) On a normal daily drive, how many miles are driven and how many cigarettes are smoked
   a. Miles driven average daily: __________

   b. Cigarettes smoked on the average daily drive: ______

7) When passengers smoke in the vehicle what is the location of the windows:
   a. Open
   b. Half open
   c. Closed

What is the location of the windows when the car is not being used:

d. Open
e. Partially opened
f. Closed

8) How often is the vehicle cleaned:
    a. Daily
    b. Weekly
    c. Monthly
    d. Greater than monthly

9) What form of cleaning is used when the vehicle is cleaned:
    a. Home vacuum
    b. Professional Vacuum (car wash, or similar)
    c. Professional service (Detailer)

10) When was this vehicle cleaned last: ________________
Day / Month / Year

11) What percent of the driving is:
    a. Freeway: ______
    b. Local / city: _____
    c. Rural / dirt roads: _____

12) Where is the vehicle housed:
    a. City / urban (on paved road)
        i. Garaged
            1. Yes
            2. No
    b. Country / Rural (on dirt road)
        i. Garaged
            1. Yes
            2. No

FOR OFFICIAL USE ONLY FOR THE STUDY INVESTIGATOR USE ONLY

Car interior Volume: (ft^3) ____________________ Research ID#:_______
Cleaning method Used: ___________
Temp: ______________
Relative Humidity: _______________
$PM_{2.5}$ initial: ______________ Nicotine sample # prior
$PM_{2.5}$ Post: _______________ Nicotine sample # after