Occupational exposure to chemicals, and health outcomes, among nail technicians in Johannesburg, South Africa

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Declaration

I, Goitsemang Keretetse, declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg, South Africa. It has not been submitted before for any degree or examination at any other University.

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Signature

24 day of August 2023 in Johannesburg, South Africa

Dedication

I dedicate this work to my loving husband,

Moagi,

and my precious children,

Naledi and Oratile.

My love for you can never be quantified.

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Abstract

Introduction: Nail technicians are exposed to chemicals emitted from activities performed in nail salons, including simple buffing of nails, basic manicures and pedicures, application of nail polish, and the application and sculpting of artificial nails. The various products used during these processes may contain volatile organic compounds (VOCs), which pose a health risk to both the nail technicians and their clients. Associated health effects include skin, eye, and respiratory irritation, neurologic effects, reproductive effects, and cancer. The aim of this study was to assess nail technicians' exposures to chemicals from nail products and their health effects within the formal and informal sectors in Johannesburg, South Africa. In this study, informal nail technicians are defined as those working in nail salons that are not licensed or registered with any formal enterprise or establishment, or in their own capacity. The objectives were 1) to estimate the prevalence of self-reported symptoms associated with the use of nail products, 2) to measure exposures to chemicals in nail products used in the formal and informal nail salons, 3) to investigate the feasibility and reliability of self-assessment of exposure as a method of estimating exposure to chemicals, and 4) to investigate the association between respiratory symptoms (chronic and acute) and chemical exposures in both formal and informal nail technicians.

Methods: This was a cross-sectional study. A questionnaire, adapted from other studies, was piloted before being administered to the participating nail technicians. Data were collected from 54 formal and 60 informal nail technicians, regarding sociodemographic characteristics, perceptions of working with nail products, and self-reported symptoms of associated health effects.

A subset of 20 formal and 20 informal nail technicians was conveniently selected from the 114 participants for the exposure assessment phase. The two groups were further divided into two groups of 10 for the controlled/expert exposure assessment (CAE) and the self-assessment of exposure (SAE). Personal 8-hr exposure measurements were performed using VOC and formaldehyde passive samplers attached to the participant's breathing zone over three consecutive days. For the SAE approach, participants conducted their own exposure measurements, while the CAE approach was fully conducted by the principal researcher. Task-based measurements were carried out using a photoionization detector (PID) to measure peak concentrations during specific nail application activities. A probabilistic risk assessment was conducted to estimate the carcinogenic and non-carcinogenic life time risks from exposure to VOCs. Chemical analysis was conducted by a SANAS-accredited laboratory. After correcting for their respective evaporation rates, relative to the evaporation rate of d-limonene (the VOC with the lowest evaporation rate), the adjusted total VOC (TVOC) concentrations were calculated using the 13 VOCs that were detected at a frequency of 30% or more. VOC concentration data below the limit of detection (LoD) were imputed, using the regression on order statistic (Robust ROS) approach. The self-reported symptoms were categorised into neurological effects, respiratory effects, eye irritation, and skin irritation. The ACGIH additive effects formula was used to calculate the combined respiratory effect of selected VOCs. Different statistical tools were used to analyse the data for each objective.

Results: Formal and informal nail technicians used different nail products, performed different nail applications, serviced different mean numbers of clients, and were exposed to different concentrations of selected VOCs. Acetone concentrations were higher in formal nail salons, due to the soak-off method used for removing existing nail applications, while methyl methacrylate (MMA) concentrations were higher in informal nail salons - related to acrylic methods being used more frequently in the informal than the formal nail salons. All VOC concentrations were below their respective occupational exposure limits, with the exception of formaldehyde (0.21 mg/m^3). TVOC levels were higher in formal nail salons, due to the bystander effect from multiple nail technicians performing nail applications simultaneously. Sixty percent of the informal nail technicians reported health-related symptoms, compared to 52% of the formal nail technicians, and informal male nail technicians reported more symptoms than their female counterparts. All nail technicians' median and 95th percentile non-cancer risks exceeded the acceptable risk of 1 for xylene, 2-propanol, and benzene, while the cancer risk estimates (medians and 95th percentiles) for benzene and formaldehyde exceeded the US EPA cancer risk threshold of 1 x 10^{-6}.

Conclusion: This is the first study to assess exposures to VOCs in the often-overlooked informal sector and compare these exposures with those in the formal

sector of the nail industry. Personal breathing zone concentration data for nail salon workers were generated in this study, including the informal sector, which is always challenging to access for research. Although banned in many countries, MMA is still used in South Africa in the informal nail sector. The SAE study showed that participatory research is feasible and enables a more reliable estimate of the exposure by expanding the amount of data. Using a combination of shift and task-based measurements was particularly effective in creating exposure profiles of employees and identifying activities that require targeted interventions. There is a need for the nail industry, especially the informal salons, to be more closely regulated, concerning the hazardous chemicals frequently encountered in nail products. Nail salons should reduce exposure frequency by regulating working hours, making informed decisions regarding the procurement of nail products, and adopting safe work practices to reduce emissions from harmful chemicals and thus exposure among nail salon workers and their clients.

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“The LORD bless you and keep you; the LORD make his face shine on you and be gracious to you; the LORD turn his face toward you and give you peace.”

Numbers 6:24-26 NIV

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Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
AM	Arithmetic mean
ANOVA	Analysis of variance
AT	Average time/lifetime
ATSDR	Agency for Toxic Substances and Disease Registry
BW	Body weight
CAE	Controlled/expert assessment of exposure
CBD	Central business district
CDI	Chronic daily intake
CNS	Central nervous system
CO_2	Carbon dioxide
COGTA	Cooperative Governance and Traditional Affairs
COVID-19	Coronavirus disease
CR	Cancer risk
CS_2	Carbon disulfide
CSF	Cancer slope factor
DBP	Dibutyl phthalate
DDT	Dichlorodiphenyltrichloroethane
DF	Detection frequency
DNA	Deoxyribonucleic acid
DNPH	2,4-dinitrophenylhydrazine
EA	Ethyl acetate
ED	Exposure duration
EF	Exposure frequency
EMA	Ethyl methacrylate
GC-FID	Gas chromatography with a flame ionization detector
GC-MS	Gas chromatography-mass spectrometry
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
GM	Geometric mean
GSD	Geometric standard deviation

HPLC	High-pressure liquid chromatograph
HQ	Hazard quotient
HREC	Human Research Ethics Committee
HVAC	Heating, ventilation and cooling
IARC	International Agency for Research on Cancer
ICLS	International Conference of Labour Statistics
IOHA	International Occupational Hygiene Association
IQR	Interquartile range
IR	Inhalation rate
IRIS	Integrated risk information system
IR_{wd}	Inhalation rate per workday
KAP	Knowledge, attitudes and practices
LEV	Local extraction ventilation
LoD	Limit of detection
LoQ	Limit of quantification
MCDA	Multi-criteria decision analysis
MEK	Methyl ethyl ketone
MIBK	Methyl isobutyl ketone
MMA	Methyl methacylate
MMPA	Mine medical professionals' association
NAS	National Academy of Sciences
nGAP	New Generation of Academics Programme
NIOSH	National Institute of Occupational Safety and Health
NO_2	Nitrogen dioxide
NOSQ	Nordic occupational skin questionnaire
NRF	National Research Foundation
NT	Nail technician
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PBB	Polybrominated biphenyls
PCB	Polychlorinated biphenyls
PEL	Permissible exposure limits
PF	Phenol formaldehyde

PID	Photoionization detector
PM	Particulate matter
PPE	Personal protective equipment
ppm	Parts per million
REL	Recommended exposure limits
RfC	Inhalation reference concentration
ROS	Regression on order statistic
SAE	Self-assessment of exposure
SAIOH	Southern African Institute for Occupational Hygiene
SANAS	South African National Accreditation System
SDS	Safety data sheet
Stats SA	Statistics South Africa
TLV	Threshold limit value
TSFR	Toluene sulphonamide formaldehyde
TVOC	Total volatile organic compounds
TWA	Time weighted average
UF	Urea formaldehyde
UK	United Kingdom
US EPA	United States Environmental Protection Agency
US FDA	United States Food and Drug Administration
USA	United States of America
UV	Ultraviolet
VAT	Value-added tax
VOC	Volatile organic compound
VOEL	Vietnam occupational exposure limit
WHO	World Health Organization
WHr	Working hours
WIEGO	Women in Informal Employment: Globalizing and Organizing

Definitions of Terms

Adjusted total volatile organic compounds (adj. TVOC): The total of the selected VOCs' concentrations per subsector, each corrected by their respective evaporation rate relative to the lowest evaporation rate of the selected VOC, i.e. d-limonene.

Additive effect: This action occurs when the combined effect of two or more chemicals is equal to the sum of the effect of each agents given alone (they do not interact in a direct way). Other mixtures will include agents that act on the same organs, or by similar mechanisms, so that the effects reinforce each other and the agents are additive in their effect.

Average lifetime: The time period over which the dose is averaged (year)

Breathing zone: The volume surrounding a worker's nose and mouth from which he/she draws breathing air over the course of a work period. This zone can be pictured by inscribing a sphere of a 300 mm radius extending in front of the face and measured from the midpoint of an imaginary line joining the ears.

Bystander effect: Exposure to chemical concentrations from 'background' emissions resulting from co-workers' activities.

Carcinogen: A substance, organism or agent capable of causing cancer.

Cancer Risk: The incremental probability of developing cancer during a lifetime due to exposure to a potential carcinogen. If the value of CR exceeds 1×10^{-4}, it represents a lifetime carcinogenic risk to the human body.

Censored data: A set of data in which some values are unknown because they are not observed or because they fall below the minimum or above the maximum value that can be measured by the scale used, i.e. data reported as below the limit of detection (LoD).

Citizen science: A voluntary collaboration among scientists and non-specialists to achieve both scientific and societal goals, is an emerging form of scientific inquiry that is growing in popularity in environmental sciences.

Controlled exposure assessment (CAE): An exposure assessment methodology whereby the process or measuring exposure is fully supervised by an expert.

Controlled group: A subpopulation of participants in Group 1, whose personal exposure measurements were conducted and supervised by the principal investigator. This is referred to as the controlled exposure assessment group.

Control measures: This includes actions that can be taken to reduce the potential of exposure to the hazard, or the control measure could be to remove the hazard or to reduce the likelihood of the risk of exposure to that hazard being realised.

Diffusion sampling: Passive or diffusive sampling relies on the unassisted molecular diffusion of gaseous agents (analytes) through a diffusive surface onto an adsorbent.

Exposure assessment is the process of measuring or estimating the magnitude, frequency, and duration of human exposure to an agent in the environment, or estimating future exposures for an agent that has not yet been released.

Formal nail salon: nail salons that are licensed and registered, some of which are part of a franchise.

Hazard quotient (HQ): The ratio of the potential exposure to a substance and the level at which no adverse effects are expected. It is calculated to evaluate the potential for non-cancer health hazards to occur from exposure to a contaminant with available non-cancer health guidelines (i.e. MRLs, RfDs, RfCs).

Health risk assessment: The process to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future.

Informal nail salon: nail salons that are not licensed or registered with any formal enterprise or establishment, or in their own capacity.

Multi-Criteria Decision Analysis (MCDA): A decision support tool/method which aims to evaluate alternatives based on multiple criteria using systematic analyses which overcome the limitations of an unstructured individual or group decision-making. It quantifies both scientific and decision-makers values and views and also develops a system of performance metrics consistent with regulatory requirements.

Nail application: Treatment of natural nails (buffing and nail polish application, basic manicure and pedicure) and/or artificial nail application (acrylic method or gel application).

Non-detect: An analytical sample where the concentration is deemed to be lower than what could be detected using the method employed by the laboratory.

Robust regression on order statistics (ROS): A semi-parametric method that can be used to estimate means and other statistics with censored data.

Self-assessment of exposure (SAE): An exposure assessment methodology whereby the worker conduct full-shift unsupervised measurements.

Preface

I am registered as an occupational hygienist with the Southern African Institute of Occupational Hygiene (SAIOH). I have more than 14 years of practical experience in occupational hygiene, covering the mining and non-mining industries. Having worked in the field of occupational hygiene as a consultant and, later, as a resident occupational hygienist for one of the parastatal organisations, I engaged with workers across various industries and saw, first hand, the conditions under which they work and the occupational hazards they encounter on a daily basis. Year in and year out, we assessed workplace exposure hazards and recommended control measures to mitigate occupational risks. The focus was on large manufacturing companies, mines and corporations, which were regulated by legislation, and those who could afford the services of consulting companies to assess their exposures and help them to comply with legislative requirements. Small and medium enterprises and, more so, businesses in the informal sector have unfortunately been excluded from the process due to financial constraints and the unregulated nature of most of these businesses.

In 2015, a South African radio station spiked an interest in my supervisor and me when it raised concerns about chemicals in nail salons and the potential harm they pose to nail salon workers. This was a result of reports in the United States of America, and media interest in an article in the New York Times by Sarah Maslin titled, "The price of nails", where she explored labour practices and working conditions of New York nail salons and the experiences of nail salon workers. Reports of poor labour practices, long working hours, exposure to hazardous chemicals and complaints of ill health among nail salon workers compelled me to look at the situation in South Africa.

The nail industry has grown globally and locally over the last two decades. In South Africa, the number of nail salons has increased since the 1900s, with a spike in the informal sector of this industry in recent years. Although a lot of research is ongoing in other countries, looking at working conditions and exposure to chemicals in this industry, very little research has been done in South Africa.

My PhD research addressed nail technicians' exposure to chemicals emitted from activities conducted in nail salons and investigated reported symptoms among formal and informal nail technicians. This work highlights the nature of the nail care industry in South Africa and also brings attention to the often-overlooked informal sector of this industry.

This PhD study did not come without challenges. There were several hurdles that I experienced, which had significant impacts to the study.

During the recruitment phase, formal and informal nail salons were visited to introduce the study to the nail salon owners and nail technicians, with the intention of recruiting them into the study. The first challenge was accessing some of nail salons in the formal sector. Although permission was initially granted by the management from the participating nail salon brand head office, their franchise partners had reservations about the study taking place at their nail salons, citing concerns about the potential impact of the study findings on their business. This led to delays in commencing with data collection at these formal nail salons. The matter was resolved through several meetings, in person, which involved communicating with the parties concerned and assuring them of the study's ethical considerations and confidentiality of all data and findings.

The informal nail salons were located in the Braamfontein area, near the Johannesburg central business district (CBD). Many of these nail salons were nested within hair salons, and the majority of them were owned by foreign nationals. During the recruitment phase, we were met with a lot of resistance from the informal nail salons; some of the salon owners not willing to engage with us. Based on our observations, the reasons for declining to participate in the study included, among others, fear of victimization and suspicion among undocumented individuals of being reported to authorities. This affected our sampling campaign and hence we chose convenience sampling over random sampling.

In mid-October 2015, a student-led protest movement, dubbed #FeesMustFall, began in South Africa. The goals of the movement were to stop increases in university student fees and to increase government funding of universities. These protests, which started at the University of the Witwatersrand, soon spread to all government-funded universities. By January 2016, the scope of the #FeesMustFall protests had broadened and complaints expanded to student accommodation, language of instruction policies (primarily at the historically white universities), and outsourcing of support staff such as cleaners, gardeners and security guards. The protests rapidly turned violent at some universities. This led to the suspension of academic programmes, damage to property, and the injury and arrest of some students. The University of the Witwatersrand, situated in Braamfontien, was at the heart of these unrests and, consequently, the informal nail salons from which I was recruiting study participants were also affected.

When all the dust settled on student protest issues, I was able to complete the recruitment phase of my study and commence with data collection with the assistance of my field workers. However, on 1 September 2019, xenophobic protests broke out in Jeppestown and the Johannesburg CBD, accompanied by riots and looting of shops owned by foreign nationals. The protests spread from the CBD to other parts of the city of Johannesburg. Many of the businesses in Braamfontein and the surrounding areas were closed out of fear of falling victim to these violent attacks.

Further delays were encountered when the COVID-19 pandemic reached South Africa. President Cyril Ramaphosa declared a national state of disaster, and the country was locked down from 27 March 2020. All data collection plans were put on hold as there was no access to the study sites. On 17 August 2020 the restrictions were lowered to Alert Level 2 and most businesses were allowed to start operating. Attempts to engage with nail salon owners and managers with regard to resuming data collection were not successful. Most companies were in a recovery phase after the crippling effects of the lockdown, and the nail salons were strictly focused on recovering their clientele and financial losses. They could not accommodate what they perceived to be potential interruptions or distractions from the research activities at their nail salons.

Only at the beginning of December 2020 was access granted at two of the study sites, and data collection resumed. The data collection was further disrupted when three other nail salons, which had agreed to participate, closed down as a result of the financial impact of the lockdown. The remainder of the nail salons that were willing to continue in the study opted to temporarily withdraw as they could not accommodate us during the month of December - a month which they deemed to be their busiest time of the year.

Another postponement (to a later date in February 2021) occurred in the second wave of the pandemic. Subsequent to this, data collection continued throughout the remainder of the year in the formal nail salons, albeit slowly and inconsistently.

Despite the above-mentioned challenges, I was able to complete my data collection and analysis and, ultimately, write up this PhD thesis.

Overview of the PhD thesis layout

This PhD is written in a publication format, and presented in six chapters. The first chapter introduces the nail salon industry and the activities carried out in the salons, as well as related potential exposures and health effects. The chapter highlights the rationale of the study and includes the aims and objectives. Chapter two is a review of the literature related to nail salon activities and characteristics, chemical exposures and related factors, volatile organic compounds (VOCs) and their classification, exposure assessment methodologies, and health effects associated with exposure to VOCs in nail salons. The third chapter details the methodology that was followed to address the objectives of the study. This is followed by chapter four, which is a summary of four papers (published and submitted) that emanated from this research. The papers are presented in Appendices 1 to 4. The co-authors and the journals have approved the inclusion of the papers in this thesis (Appendix 5). Chapter five is the discussion, which ties the research findings together. The policy and research implications of the findings are described in detail, and recommendations are made to address the outstanding issues identified during the course of the investigation. Last, chapter six comprises the overall conclusion of the research.

CHAPTER 1: INTRODUCTION

This chapter provides a background to the PhD study and introduces key topics that are addressed in this thesis. The PhD thesis describes occupational exposures to volatile organic compounds and the health impact on nail technicians in the formal and informal sectors of the beauty industry. The problem statement and the rationale of the study are outlined in this chapter, followed by the aims and objectives of the research conducted. The chapter concludes with an overview of the thesis layout.

1.1. Background

Globally, the professional nail care industry has seen significant growth over the last two decades, with numerous nail salons and nail care professionals entering the beauty industry (Goldin et al., 2014, Zhong et al., 2019, Harrichandra et al., 2020, Lteif et al., 2020). In the USA alone, there were more than 58 000 beauty salons with more than 350 000 licensed nail technicians in 2006 (Goldin et al., 2014). In 2017, there were more than 56 000 nail salons and 440 000 nail technicians in the USA (Ma et al., 2019). South Africa has also seen growth in the beauty industry since the 1900s (Roy, 2017). Nail care services, as part of the beauty industry, are located within both the formal and informal sectors in South Africa. The 15th International Conference of Labour Statistics (ICLS) defined the informal sector according to the following criteria: "non-registration of the enterprise in terms of national legislation such as taxation or other commercial legislation; non-registration of employees of the enterprise in terms of labour laws; or small size of the enterprise in terms of the numbers of people employed" (Chen, 2012). Statistics South Africa defines the informal sector as those businesses that are unregistered (Statistics South Africa, 2021b). In this PhD study, formal nail salons were defined as formalised and registered businesses, some of which are franchises with formal employment structures, regulated working hours, and monthly salaries. Informal nail salons were those businesses that are not registered or regulated by the government, are mostly self-owned or part of an existing business such as a hair salon, and where employees/workers (who may be the business owners) have irregular working hours and unstable wages/incomes.

The beauty industry, as a whole, was badly hit by the impact of the COVID-19 pandemic. Many salons closed while others downscaled, cutting staff numbers. This required many salons to find new ways of staying afloat and engaging with their clients. During the shutdown, nail professionals focused on promoting their businesses on social media to remain relevant (Schütz, 2021, Davis, 2021). To ensure the safety of their clients and employees during the COVID-19 pandemic, nail salons took several precautions such as increasing the frequency of sanitation and disinfection, requiring clients and employees to wear face coverings, maintaining social distancing protocols by limiting the number of customers in the salon at any given time, and implementing online bookings and contactless payment systems. As COVID-19 restrictions were lifted and customers began to get vaccinated, most nail salons reopened and loyal customers started to return (Davis, 2021).

Nail adornment dates back to the 18th century when ancient Egyptian and Asian cultures used coloured nails made from dyed henna and crushed flowers as a symbol of status. The first American nail salon is said to have opened in 1878, which made way for more nail salons and further development of the art of nails in the 1990s (Shapiro, 2014). The dominance of the American nail industry by Vietnamese immigrants can be traced back to the 1970s. In a 2018 report published by the University of California, Los Angeles Labor Center, it was found that 79% of workers in the nail industry are immigrants, mainly consisting of women born in Vietnam (Sharma, 2018).

Nail care has evolved from simple grooming to a means of self-expression. Over the years, the nail industry has seen an explosion of styles and trends with the introduction of nail art and a wide variety of designs. Consumers have shifted away from the conservative "French design" to more unique and elaborate nail art styles that reflect their personalities and suit particular occasions.Many establishments in South Africa and beyond offer nail care services either as a stand-alone offering or as part of a broader cosmetic business (Alaves et al., 2013).

Different methods are used during treatments of natural nails and application of artificial nails, and all are associated with potential health hazards. Treatments range from simple buffing of the nails, to basic manicures, to sculptured artificial nails

(Moossavi and Scher, 2001, Jefferson and Rich, 2012). Artificial nail products are made from many chemicals, which may pose health risks to nail technicians and their clients. Working with both natural and artificial nails involves the use of solvents, such as acetone, ethyl acetate and n-butyl acetate. In addition to these, artificial (acrylic) nail applications make use of acrylic polymers and monomers (Reutman et al., 2009). Nail polish removers contain acetone and butyl acetate, which may lead to headaches, dizziness, and eye, skin and throat irritations (Roelofs et al., 2008, OSHA, 2017, Pavilonis et al., 2018). Nail polish potentially contains formaldehyde, dibutyl phthalate (DBP) and toluene- a combination sometimes referred to as the 'toxic trio' (OSHA, 2017). Toluene can affect the central nervous system and cause reproductive harm (U.S. EPA, 2005, ATSDR, 2014, OSHA, 2017). Formaldehyde is a known carcinogen and exposure to DBP has been linked to reproductive health problems (Alaves et al., 2013, IARC, 2006, U.S. EPA, 2010). In addition to this trio, there are many other harmful chemicals used in nail care products. Studies have reported that nail technicians are exposed to airborne acetone, toluene, butyl acetate and methyl methacylate (MMA). These studies have also found that nail technicians experience a significantly higher proportion of work-related respiratory, neurologic, eye, skin, and musculoskeletal complaints compared to office workers (Harris-Roberts et al., 2011, Park et al., 2014, Lteif et al., 2020, Tran et al., 2020). Table 1.1, adapted from the US U.S. EPA (2007), Roelofs et al. (2008) and Spoelstra (2010), lists the different chemicals that can be found in products used in nail salons, and the associated self-reported health effects.

The basic manicure performed at a nail salon involves the removal of old nail polish with a polish remover that might contain acetone, ethyl acetate, butyl acetate or methyl ethyl ketone. Nail polish is then reapplied, in most cases. Nail polishes are a mixture of different components (Goldin et al., 2014, Moossavi and Scher, 2001, Reutman et al., 2009, Roelofs et al., 2008, Spoelstra, 2010, White et al., 2015, Young et al., 2018), such as:

- A film former, which is a non-sensitizing, durable and waterproof component;
- A thermoplastic resin in the form of toluene sulphonamide formaldehyde (TSFR), which allows adhesion of the polish to the nail, and improves gloss;

- Plasticizers in the form of dibutyl phthalate and camphor, which improve flexibility and adhesion, and also prevent shrinkage;
- Solvent extenders, which might include toluene, butyl or ethyl acetate, and isopropyl alcohol; and
- A pigment component.

Artificial nails are made by gluing preformed plastic nails or tips over the natural nail. The glue or adhesive used is ethyl cyanoacrylate. Another method of creating artificial nails is by sculpting acrylic nails. These are made with a two-part acrylic liquid monomer and powder polymer that is cured at room temperature. The paste is moulded onto the natural nails and then shaped until it hardens. Next, the nail is filed into the desired shape and length, and then coated with a nail finish or top coat (Moossavi and Scher, 2001).

One of the main chemical monomers found in these acrylic nail products is MMA (U.S. FDA, 2013b, OSHA, 2017). The United States Food and Drug Administration (FDA) banned the use of MMA in 1974 due to its skin sensitization properties, which may potentially lead to allergic contact dermatitis (U.S. FDA, 2013a). Exposure to MMA is known to cause eye, skin and respiratory tract irritations; it is also associated with asthma (Park et al., 2014, Reutman et al., 2009). MMA has been replaced with ethyl methacrylate (EMA), a similar chemical considered to be less toxic than (U.S. FDA, 2013b, Reutman et al., 2009). However, most countries continue to use nail products that contain MMA, as they are cheaper than those containing EMA (Alaves et al., 2013, Galloway and Burr, 2006, Lamplugh et al., 2019, Quach et al., 2011, Zhong et al., 2019). Acetone and EMA have low odour thresholds, meaning that most people can smell them at levels below their recommended exposure limits (Galloway and Burr, 2006) (set to protect workers from adverse health effects of hazardous chemical substances exposure by inhalation).

Gel application is another method in which nails are coated with premixed methacrylate and then light-cured, using ultraviolet (UV) light (Gjølstad et al., 2006, Moossavi and Scher, 2001, Reutman et al., 2009). The gel mixture does not have an unpleasant sharp smell, unlike the acrylic liquid monomer. Some chemicals do not have a sharp or distinct smell, which may give a false impression that they are safe to work with.

Different methods are used to assess exposure to chemicals emitted from nail products. These range from personal sampling using active sampling pumps to passive sampling by means of passive samplers. Exposure measurements can be taken at strategic places to assess emissions from the source, or they can be attached to the lapel of the worker to assess personal exposure. Direct reading instruments can also be used for real-time monitoring of exposure.

Table 1.1 Chemical substances contained in nail products and the associated health effects

Nail Products	Hazardous Chemical substance	Potential health effect
Nail polish	Ethyl acetate[1]	Irritation eyes, skin, nose, throat; dermatitis
	Butyl acetate[1]	Irritation eyes, skin, upper respiratory system; headache, drowsiness
	Ethyl alcohol[1]	Irritation eyes, skin, nose; headache, CNS (central nervous system) syndrome; cough; liver damage; anaemia; reproductive effects
	Isopropyl alcohol [1] Acetone[1] Methyl ethyl ketone[1]	Irritation eyes, nose, throat; CNS syndrome, headache, light headedness, dizziness, nausea; dry, cracking skin; dermatitis
	Toluene[1]	Irritation eyes, nose, throat; headache; CNS syndrome; dermatitis; dilated pupils, lacrimation; anxiety, muscle fatigue, insomnia; paraesthesia; liver, kidney damage
	Xylene[1]	Irritation eyes, nose, throat; headache; CNS syndrome; corneal damage; dermatitis; reproductive effects
	Dibutyl phthalate[1]	Irritation eyes, upper respiratory system, stomach; reproductive and developmental effects (miscarriage and infertility)
	Toluene Sulfonamide-Formaldehyde[1] Resin	Irritation eyes, skin, throat; dermatitis; suspected carcinogen
	Titanium dioxide	Lung fibrosis; potential occupational carcinogen
Nail polish removers	Acetone[1] Ethyl acetate[1] Butyl Acetate[1]	Refer to acetone Refer to ethyl acetate Refer to butyl acetate
Artificial nails *Includes: acrylic polymers, hardeners, primers, dehydrators*	Ethyl methacrylate[1] Methyl methacrylate[1] Butyl methacrylate	Irritation eyes, skin, nose, throat; allergic contact dermatitis; respiratory sensitizer (asthmagen)
	Methacrylic acid[1]	Irritation eyes, skin, mucous membrane; eye, skin burns
	Methyl ethyl ketone[1]	see above
Nail tips adhesives	Ethyl cyanoacrylate[1]	Irritation eyes, skin, nose, throat; allergic contact dermatitis, skin sensitizer
Artificial nail removers	Acetone[1]	see above
	N-methyl pyrrolidone	Dermatitis, reproductive effects
	Acetonitrile	Irritation nose, throat; asphyxia; nausea, vomiting; chest pain; CNS syndrome; convulsions; in animals: liver, kidney damage
Disinfectants	Formalin/ paraformaldehyde (formaldehyde) [1]	Irritation eyes, nose, throat, respiratory system; lacrimation; cough; wheezing; dermatitis; known carcinogen
	Isopropyl alcohol[1]	Refer to isopropyl alcohol
	Bleach (sodium hypochlorite)	Irritation eyes, nose, throat, respiratory system; skin sensitizer
	Hospital grade disinfectants, e.g. Quaternary ammonium compounds	Respiratory sensitizers (asthmagens)

Adapted from U.S. EPA (2007), Spoelstra (2010) and Roelofs et al. (2008)

[1] Chemicals that were measured in this study

1.2. Rationale for the study

Much of the research on exposure to chemicals among nail technicians has been conducted internationally. Studies in Korea, the United Kingdom (UK), Vietnam, and the USA have reported musculoskeletal disorders, respiratory symptoms, skin problems and headaches in nail technicians (Harris-Roberts et al., 2011, Park et al., 2014, Quach et al., 2011, Reutman et al., 2009, Roelofs et al., 2008). Only one study by Spoelstra (2010), has been done in South Africa, despite the continued growth of this industry and evidence of the hazardous nature of chemicals found in nail products. She evaluated potential respiratory and dermal exposure of nail technicians to acetone, formaldehyde, ethyl methacrylate, methyl methacrylate, toluene and xylene. The findings revealed that nail technicians were exposed to volatile organic compounds (VOCs) from nail products at levels below the recommended South African occupational exposure limits (DEL, 2021). Although the measured VOC levels were low, the unknown effects of chronic low level exposure to solvents are still a concern. Spoelstra also reported the presence of MMA, which is indicative of the continued use of products containing MMA despite the ban from the US FDA. The study findings also suggested that there was a significant correlation between dermal exposure and airborne ethyl methacrylate. However, the study was limited by the small sample size of 15 nail technicians, and the demographic characteristics of the nail technicians or health effects related to exposure were not considered. Although studies on nail technicians' exposures to chemicals have been conducted, none has compared working conditions and exposure factors between established formal nail salons and informal nail salons.

The research presented in this thesis highlights the nature of the nail care industry in South Africa and brings attention the often overlooked informal sector of this industry.

1.3. Aim and objectives

The aim of this research was to assess nail technicians' exposures to chemicals from nail products and to describe reported health effects, within the formal and informal sectors in Johannesburg, South Africa.

Objectives

1. To estimate the prevalence of self-reported symptoms associated with the use of nail products in formal and informal nail salons in Johannesburg, South Africa.
2. To measure the level of exposure to chemicals in nail products used in the formal and informal nail salons.
3. To investigate the feasibility and reliability of self-assessment of exposure as a method of estimating exposure to chemicals used in the formal and informal nail salons.
4. To investigate the association between respiratory symptoms (chronic and acute) and chemical exposures in formal and informal nail technicians and conduct a probabilistic risk assessment to estimate the carcinogenic and non-carcinogenic risks associated with exposure to volatile organic compounds.

CHAPTER 2: LITERATURE REVIEW

This chapter comprises a review of the relevant literature from published international and local studies, and also serves to identify the knowledge gaps. The chapter emphasises nail treatment activities, focusing on exposures to volatile organic compounds (VOCs) and potential health effects from such exposures. Topics related to exposure assessment methodologies and human health risk are also outlined in this chapter, which concludes by highlighting the knowledge gaps in the literature which helped to form the basis of this PhD research.

2.1. Nail applications and products used in the nail salon industry

Nail application activities involve the use of a variety of products which contain chemicals with the potential to cause adverse health effects. Nail services offered in nail salons include basic manicures and pedicures, application of nail polish, UV gel and acrylic and artificial nails (Moossavi and Scher, 2001, Jefferson and Rich, 2012). Various products containing a cocktail of chemical ingredients are used for different purposes throughout each nail application. The chemicals include solvents such as aromatics hydrocarbons (toluene, ethyl benzene, xylene), aldehydes (formaldehyde), esters (ethyl acetate, butyl acetate, vinyl acetate, methyl methacrylate (MMA), ethyl methacrylate (EMA)), ketones (acetone and methyl ethyl ketone), alcohols (ethanol, isopropyl alcohol, and n-butyl alcohol), plasticizers (dibutyl phthalate, triphenyl phosphate), and turpentines (pinene, limonene, camphor, menthol) (Park et al., 2014, Ceballos et al., 2019, Craig et al., 2019).

2.2. Occupational exposure to chemicals found in nail products and related factors

Although nail technicians are repeatedly exposed to chemical substances with which they come into contact during their daily use of nail products, different studies have reported conflicting findings with regard to exposure levels. The levels of exposure have been reported to be lower than the respective occupational exposure limits (OELs) in most studies conducted in the nail industry (Gjølstad et al., 2006). In a study published by Grešner et al. (2015), the levels of exposure of nail technicians to volatile organic compounds (VOCs) were below their respective American Conference of Governmental

Industrial Hygienists (ACGIH) threshold limit values (TLVs). They reported statistically significant correlations between selected biomarkers of oxidative stress, DNA damage, and airborne levels of VOCs. The authors concluded that their findings might have been due to prolonged low-level occupational exposure to VOCs or other chemicals in nail salons. Findings from a Finnish study (Henriks-Eckerman and Korva, 2012) showed that exposure levels for methacrylic acid (MA), MMA, and EMA were below their respective OELs.

However, in a study in Korea, personal exposure measurements for acetone, toluene, butyl acetate and MMA exceeded the Korean OEL by 64%, 50%, 46% and 12%, respectively (Park et al., 2014). Such high exposures could be attributed to the full-shift based personal sampling used, which reflected the actual work scenario of longer working hours. Samples were also collected on weekends, which are the busiest time of the week (the most customers). The authors stated that the high exposure levels could also be attributed to the absence of local exhaust ventilation in the nail salons. Studies have reported higher emissions of VOCs from nail salons with no ventilation than those with ventilation (Pavilonis et al., 2018, Harrichandra et al., 2020). In a study conducted in Boston, US, the authors found that nail services that were being performed (e.g., pedicure, manicure, silk nails, gel nails, acrylic nails, waxing and airbrushing), increased air pollutant concentrations, and ventilation improved indoor air quality (Goldin et al., 2014). Hadei et al. (2018) found significant relationships between the concentrations of some compounds (benzene, toluene, ethylbenzene, and formaldehyde) and the number of treatments. Their findings also showed that effective ventilation reduced exposure concentrations.

In South Africa, only one study has been conducted on nail technicians' exposure to chemical substances found in nail products (Spoelstra, 2010). Spoelstra, compared exposure of nail technicians performed acrylic nail applications with those who performed UV-gel applications (Spoelstra, 2010). The results showed that 8-hour time weighted average (TWA) personal exposure to acetone, ethyl methacrylate, MMA, toluene and xylene in both groups were well below the recommended South African OELs of the individual chemicals and showed no additive effect. The average formaldehyde respiratory exposure of both exposure groups exceeded the NIOSH Recommended Exposure Limits (RELs) but was below the South African OEL and the OSHA TWA-OELs. This study also revealed the use of MMA in nail products sold in South Africa even though this chemical substance is banned by the FDA in the US.

2.3 *Volatile organic compounds* (VOCs) and their classification

VOCs are organic chemical compounds, the composition of which makes it possible for them to evaporate under normal indoor atmospheric conditions of temperature and pressure. They have an initial boiling point of less than or equal to 250 °C measured at a standard atmospheric pressure of 101.3 kPa (U.S. EPA, 2017). The World Health Organization (WHO) categorises VOCs (Table 2.1) according to the ease by which they are emitted. The volatility of organic compounds is defined and classified by their boiling points, since the higher the volatility of a compound the lower its boiling point temperature. The three main categories of VOCs are: very volatile organic compounds (VVOCs), volatile organic compounds (VOCs), and semi-volatile organic compounds (SVOCs) (World Health Organization, 1989). VOCs include a wide range of compounds such as carbonyls, organic acids, alcohols, alkanes, alkenes, aldehydes, esters, ketones and aromatic hydrocarbons. Their physical and chemical properties and their residence times in the atmosphere (ranging from a few minutes to several months) often lead to risks to the environment and human health (Mohd Hanif et al., 2021).

Table 2.1 Classification of Volatile organic compounds (VOCs)

Description	Abbreviation	Boiling Point Range (°C)	Example Compounds
Very volatile (gaseous) organic compounds	VVOC	<0 to 50-100	Propane, butane, methyl chloride
Volatile organic compounds	VOC	50-100 to 240-260	Formaldehyde, d-limonene, toluene, acetone, ethanol (ethyl alcohol) 2-propanol (isopropyl alcohol), hexanal (hexanaldehyde),
Semi volatile organic compounds	SVOC	240-260 to 380-400	Pesticides (DDT, chlordane, plasticizers (phthalates), fire retardants (PCBs, PBB)

Adapted from the WHO (World Health Organization, 1989)

DDT, dichlorodiphenyltrichloroethane; PCBs, polychlorinated biphenyls; PBB, polybrominated biphenyls

Occupational and non-occupational exposure to VOCs has been studied for many years. In a study by Masekameni et al. (2018), VOCs emissions from domestic practices were characterised using a laboratory simulation. Another study, in India, investigated the association between indoor VOCs and respiratory symptoms among children living in households that use solid fuel (Natarajan et al., 2022). A study in China, which estimated the health risk of non-occupational populations residing near a coking factory (Qin et al., 2022), indicated that biomass or coal burning was the major source of exposure. More recently, studies have been done on VOC exposures among petrol attendants (Keretetse et al., 2008, Rekhadevi et al., 2011, Salem et al., 2018), occupations associated with potential exposure to motor vehicle exhaust and/or gasoline vapour emissions (Jo and Song, 2001, Rahman and Kim, 2012), farm workers in agricultural settings (Arı et al., 2022, Norkaew et al., 2021), waste water treatment (Pitiriciu and Tansel, 2021, Zhang et al., 2019), and the painting industry (Cheng et al., 2017, Mo et al., 2021). Other researchers looked at various organic solvents among hairdressers (Hadei et al., 2018, Pexe et al., 2019, Ricklund et al., 2023, Zhong et al., 2019), as well as in the nail industry

(Alaves et al., 2013, Hadei et al., 2018, Lamplugh et al., 2019, Tran et al., 2020, Zhong et al., 2019).

2.4 Health effects and self-reported symptoms

Studies have shown that occupational exposure to chemical substances found in nail products is associated with various adverse health effects such as skin, eye and upper respiratory irritation, headaches, and occupational asthma (Harris-Roberts et al. 2011; Park, et al. 2014; White et.al. 2015). Health effects associated with nail products and the chemical substances they contain are summarised in Table 1.1.

The most commonly reported symptoms are respiratory and neurologic symptoms, eye irritation, skin problems, and musculoskeletal disorder as described in studies from Korea (Park et al., 2014), the United Kingdom (UK) (Harris-Roberts et al., 2011), Vietnam (Tran et al., 2020), Lebanon (Lteif et al., 2020), and the USA (Quach et al., 2011, Ma et al., 2019, Lamplugh et al., 2019). In a study conducted by Park et al. (2014) in Korea, the perceptions of work-related symptoms by nail salon workers were compared to those of office workers (controls). Nail technicians had a higher prevalence of work-related musculoskeletal symptoms such as neck, shoulder, upper back, arm and wrist or hand pain than the control group. In addition, nail salon workers frequently reported respiratory and neurological symptoms such as nose irritation, coughing, dizziness, headaches, throat irritation and eye irritation, while the control office workers' most frequent complaints were eye irritation and headaches. These findings correlate with those from a study conducted in the UK by Harris-Roberts et al. (2011), on 64 non-exposed office workers and 71 nail technicians. Nail technicians reported a significantly increased prevalence of nasal symptoms, work-related neck, shoulder, wrist and hand and lower back problems compared to office workers. Self-reported health effects such as skin problems, respiratory irritation, musculoskeletal disorders and headaches were reported as work-related in conjunction with poor air and offensive odours in a health-effects survey conducted among Vietnamese-American nail salon workers in Boston (Roelofs et al., 2008). In a study on Vietnamese nail technicians working in California, participants reported that they experienced acute health effects after they began working in the nail care industry (Quach, et. al., 2011). There was a high prevalence of reported eye, nose, throat, and skin irritation symptoms in a study by Tran et al. (2020) on Vietnamese nail salon workers in Danang city. The prevalence of self-reported symptoms, namely, headache, nausea, nose irritation, skin irritation, shortness of breath, and confusion was significantly higher for the nail salon workers (n = 100) than for the comparison subjects (n = 100). Among the nail salon workers, the prevalence of nose irritation was significantly higher for nail workers who were exposed to acetone at levels exceeding the Vietnam occupational exposure limit (VOEL).

Nail salon workers of Asian origin who worked in Oregon, USA, reported nose irritation and allergies as the most common health problem, and those who applied acrylic nails had a higher number of “fair” to “poor” self-reported general health conditions (White et.al. 2015). In a study by Ma et al. (2019), nail salon workers reported that they experienced symptoms that emerged since they started working in the nail industry, and that the symptoms worsened when at work. Dang et al. (2021) reported that nail technicians identified health issues that they perceived to be directly related to workplace exposures. These included symptoms experienced due to contact with nail products and poor ergonomics.

Although acute health effects related to chemical exposures in the nail care industry have been studied there are only a few studies on the long-term effects of VOCs from nail products (Hadei et al., 2018, Lamplugh et al., 2019, Tran et al., 2022). Benzene, toluene, ethylbenzene, and xylene are known to cause adverse health effects such as cancer and neurological effects. Benzene has been confirmed to be carcinogenic to humans (Group 1) by the International Agency for Research on Cancer (IARC) and a known human carcinogen (Group A) by the US Environmental Protection Agency (EPA) (IARC, 2018, U.S. EPA, 2003b). Formaldehyde has been classified as a probable carcinogen (Group B1) by the EPA’s Integrated Risk Information System (IRIS), and as a human carcinogen (Group 1) by the IARC (IARC, 2006, U.S. EPA, 2010).

2.5 Exposure assessment methodologies

Different methods are used to assess exposure to chemicals emitted from nail products. These range from personal sampling using active sampling pumps to passive sampling by means of passive samplers. Exposure measurements can be taken at strategic places to assess emissions from the source, or the sampling media can be attached to the lapel of the worker to assess personal exposure at the breathing zone. Direct reading instruments can also be used for real-time monitoring of exposure.

2.5.1. Active sampling

The US EPA Method TO-15 (U.S. EPA, 1999b) is an analytical method used to measure the concentration of volatile organic compounds (VOCs) in ambient air, indoor air, and other gas samples. It measures up to 97 VOCs from the 189 hazardous air pollutants listed in the Clean Air Act. It is used for testing grab samples of ambient air. The method involves the collection of air samples into a specially-prepared stainless steel canister (e.g. summa canister) which are then analysed using a gas chromatograph/mass spectrometer (GC/MS). The method is widely used in environmental monitoring, occupational hygiene, and indoor air quality assessments.

Active sampling of VOCs can also be done by following the NIOSH Method 2016 (formaldehyde), which uses silica gel coated with 2,4-dinitrophenylhydrazine; the NIOSH Method 1500 (aromatic hydrocarbons), using coconut shell charcoal; the NIOSH Method 2537 (MMA and EMA), using XAD-2 solid sorbent; and the NIOSH Method 1459 (methyl acrylate), using coconut shell charcoal (NIOSH, 2018). These sampling methods have been used in studies conducted in nail and beauty salons (Alaves et al., 2013, Hadei et al., 2018, Tsigonia et al., 2010, Zhong et al., 2019). The VOCs collected in the sorbent tubes were analysed using a gas chromatography/flame ionization detector (GC/FID). The sampling procedure involved the use of a calibrated personal sampling pump with a representative sampler attached to a personal sampling pump. The sampler can be attached to the lapel of a worker to measure the breathing zone concentration (Figure 2.1) or located strategically to measure ambient concentrations.

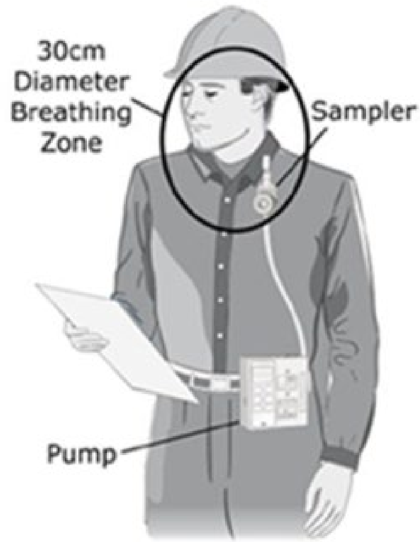

Figure 2.1 Sampling head attached to a worker's collar illustrating breathing zone. (Source: Ducting express)

At the end of the sampling period, the pump is switched off and the sampler is capped, packed securely, and transported for analysis. Formaldehyde active sampling was conducted following the NIOSH method 2016 using silica gel coated with 2,4-dinitrophenylhydrazine, in a study by Alaves et al. (2013).

Formaldehyde assessment can be carried out following the US EPA TO-11A method (U.S. EPA, 1999a) as was done in a study by Lamplugh et al. (2019). This method is used for the measurement of formaldehyde and other carbonyl compounds (aldehydes and ketones) in ambient air, utilising a coated-solid adsorbent followed by high-performance liquid chromatographic (HPLC) detection. The sampling procedure involves drawing a known volume of ambient air through a prepacked cartridge coated with acidified 2,4-dinitrophenylhydrazine (DNPH) at a 100-2000 mL/min sampling rate for an appropriate period of time. The sampling rate and time are dependent upon the carbonyl concentration in the test atmosphere. Once sampling is complete, the sample cartridges and field blanks are individually capped and placed in shipping tubes with polypropylene caps, for analysis.

Passive sampling

Passive or diffusive sampling (Figure 2.2) relies on the unassisted molecular diffusion of gaseous agents (analytes) through a diffusive surface onto an adsorbent. Unlike active (pumped) sampling, passive samplers require no electricity, have no moving parts, and are simple to use (no pump operation or calibration). Several studies have used passive personal air monitoring by attaching 3M organic vapour monitors (OVM) to the breathing zone of nail salon workers (Garcia et al., 2015, Ma et al., 2019, Park et al., 2014, Quach et al., 2011, Tran et al., 2020). Samplers were stored under 5°C until analysis. Chemical analysis was performed with gas chromatography-mass spectrometry (GC_MS). Radiello badges were used in a study by Harrichandra et al. (2020) to measure daily concentrations of ethyl acetate, toluene, and MMA over a period of three consecutive days and collocated with the direct reading instruments. The passive samplers and the direct reading instrument were positioned in a central location inside the nail salon.

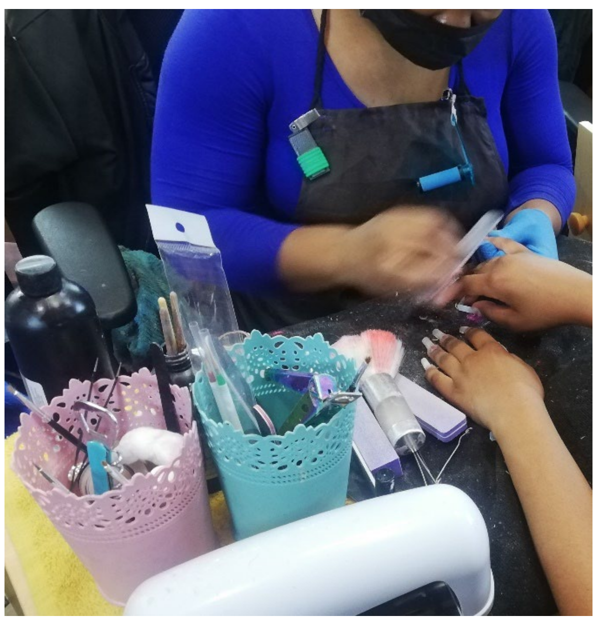

Figure 2.2 Personal passive sampling for volatile organic compounds and formaldehyde on a nail technician

Passive sampling was used in a study by Zhong et al. (2019) to assess exposure to VOCs in nail salons. Volunteers visited nail salons in Colorado with a passive sampler (10 cm long stainless tubes packed with 60/80 mesh Tenax-GR with a 0.5 cm diffusion gap) attached to their shirts or blouse collars. These samples were expected to reflect the personal exposures of the nail technicians since the distance between the samplers and the nail services being performed was comparable to that between the nail technicians and the service area.

Direct reading instruments by means of a Photoionization Detector (PID)

A Photoionization Detector (PID) operates by detecting the presence of VOCs in the air by measuring the amount of ionization that occurs when the air sample passes through the device. When the PID is turned on, a high-energy ultraviolet (UV) lamp typically with an ionization energy of 9.8. 10.6, or 11.7 eV emits light that ionizes the gas molecules in the air passing through the device (Zimmer et al., 2015). The photons from the UV lamp have enough energy to remove an electron from the gas molecules, creating positively charged ions and negatively charged electrons. The ions and electrons produced by the UV lamp are then attracted to the positively charged anode in the detector, creating a small electric current proportional to the gas' concentration in the air (Figure 2.3.).

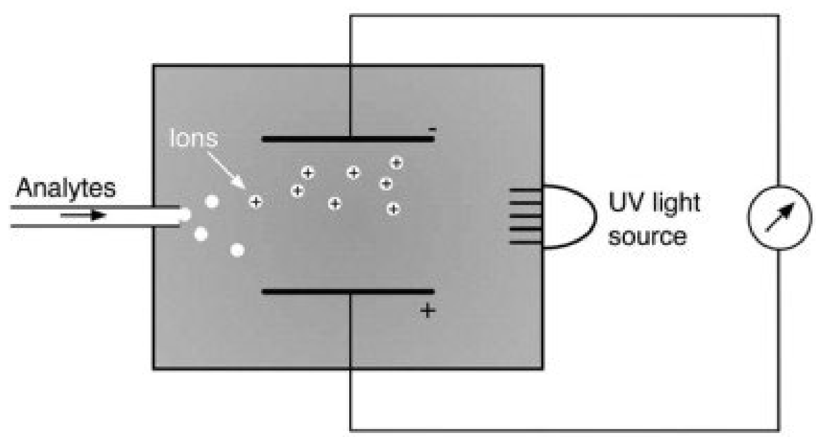

Figure 2.3 Schematic diagram showing an overview of the functioning of a photoionization detector (PID) (Stauffer et al., 2008)

The PID can be calibrated to detect specific compounds by adjusting the sensitivity and response of the device to the gas being measured. The concentration of the target gas can be determined by comparing the current produced by the gas sample with the current produced by a known reference gas (OSHA, 2014).

The advantage of the PID method is that it is very sensitive and can detect very low concentrations of gas in the air. It is commonly used in occupational hygiene, environmental monitoring, and emergency response situations to detect and measure the presence of VOCs that may pose a health or safety risk. The PIDs can be useful for identifying peaks in VOC concentration data and determining their source.

Figure 2.4 Task based exposure assessment using a photoionization detector during a nail application process

2.6 Conceptual framework

Exposure can be defined as contact between a stressor (hazard) and a receptor. The receptor can be a worker, a person residing in a community, or a consumer of product. For an exposure event to occur, three main contributing factors characterise the contact between a stressor and a receptor, viz. the amount (e.g. concentration), the duration (e.g. exposure duration, and frequency), and the location within the system (e.g. inhaled air, skin, or target tissue) (National Research Council, 2012). It is important to understand how other factors may affect the internal dose. For example, a person's inhalation rate may be affected by the level of physical activity in which they engage. It is also important to understand the exposure pathway, which defines the mechanism of release of a stressor from the source, and how it transforms along the transmission pathways until it reaches the receptor where potential contact results in an exposure event. The continuum from sources of stressors, fate in the environment, contact with human and ecologic systems, and the exposures lead to the exposure dose necessary to produce health outcomes (Huang et al., 2019).

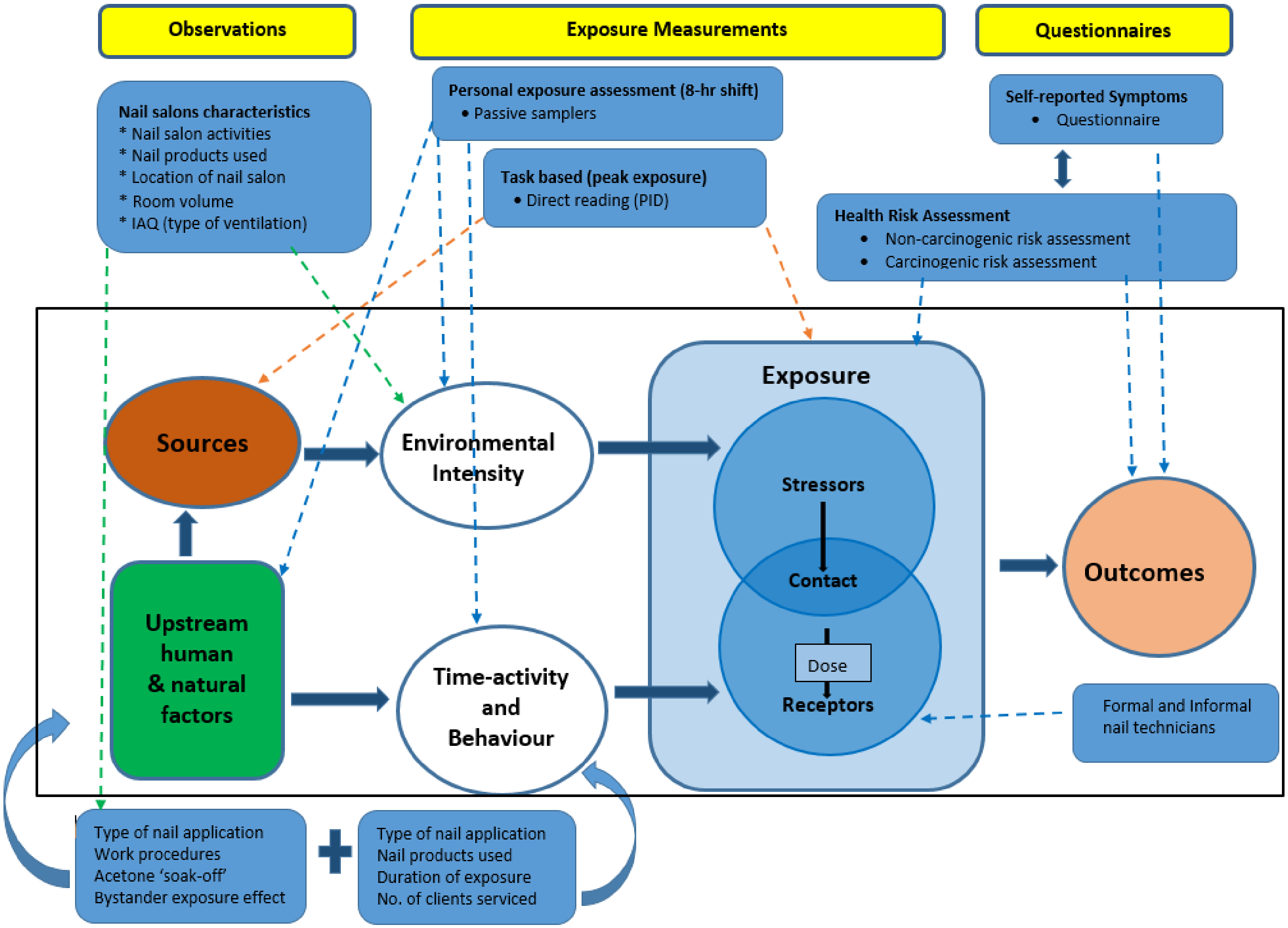

Figure 2.5 Conceptual framework showing the source-to-effect continuum relating to exposure science. (Adapted from the National Research Council (2012).

The conceptual framework for this study (Figure 2.5) illustrates the essential components of exposure science. The framework shows the linkages between sources of stressors, environmental intensity (such as pollutant concentrations), time-activity and behaviour, contact of stressors and receptors, and outcomes (Lioy and Smith, 2013). The data collection tools used to generate the necessary data to address study objectives are included.

In this context, the sources of stressors in question are the nail application activities performed by nail technicians, and the nail products. Nail technicians spend their working hours performing various activities, which involve the use of nail products containing a mixture of chemical substances, including VOCs. During these activities, potentially hazardous VOCs are released into the environment and the breathing zone of the nail technicians, resulting in exposure. The intensity of the VOCs in the environment is influenced by a range of human and natural factors, including the type of nail application, the method of application, the number of clients serviced, and the duration of the nail application. To evaluate these variables, questionnaires were administered and exposure assessments were conducted. To determine the health effects related to VOC exposure, nail technicians reported symptoms they experienced over the previous four weeks. Long-term effects were estimated by calculating carcinogenic and non-carcinogenic risk assessments.

Understanding the source-outcome model enables us to determine the crucial factors that contribute to exposure. This provides a guide for intervention strategies to minimize exposure, and will potentially lead to the development of better policies for chemicals that are used in commerce and industrial processes.

CHAPTER 3: METHODOLOGY

This chapter outlines the methodology followed when conducting this research. The overall methodological approach to the PhD is presented. The study setting is described to provide an overview of the nail salon industry in South Africa and how the formal and informal sectors are organised. The research design, the study population, and the study sample are described, as are the data collection tools and the methods followed for data collection, the chemical analysis that was conducted to quantify the individual VOCs, the data management and the data analysis. The chapter concludes with the ethical considerations addressed during the study.

3.1. Study setting

In 2021, Statistics South Africa (Stats SA) estimated the mid-year population of South Africa to be 60.14 million people. Approximately 51.1% (about 30.75 million) of the population was female and approximately 48.9% (about 29.39 million) was male. By the end of June 2022, the population of South Africa was estimated to be 60.6 million (Statistics South Africa, 2021a). Gauteng province is the province with the highest density and the largest share of the South African population, with approximately 15.81 million people (26.3%) (South African Government, 2023). Johannesburg is home to about 5.5 million people, making it the biggest metro by population size in South Africa, and it prides itself on being the economic and financial hub of the country. South Africa has the most unequal society in the world, in terms of income, with a Gini Coefficient of 0.629 (South African Government, 2023). Johannesburg is a city of contrasts – home to both wealthy and poor, residents and refugees, global corporations, and emerging enterprises. This contrast and levels of inequality has contributed to the high unemployment rate, with many people seeking employment in the informal sector. The informal sector in Johannesburg is estimated to account for 7 to 13% of the total economy of the City (COGTA, 2020). This provides a background to the study setting.

The study was conducted in nail salons in the City of Johannesburg, South Africa. The formal nail salon were located in the northern suburbs of Johannesburg, while the informal nail salons were located in Braamfontein, near the Johannesburg central business district (CBD) (Figure 3.1). The formal nail salons were franchises of one of the largest local beauty companies in South Africa, while the informal nail salons comprised unregistered nail salons, some of which operated inside hairdressing salons.

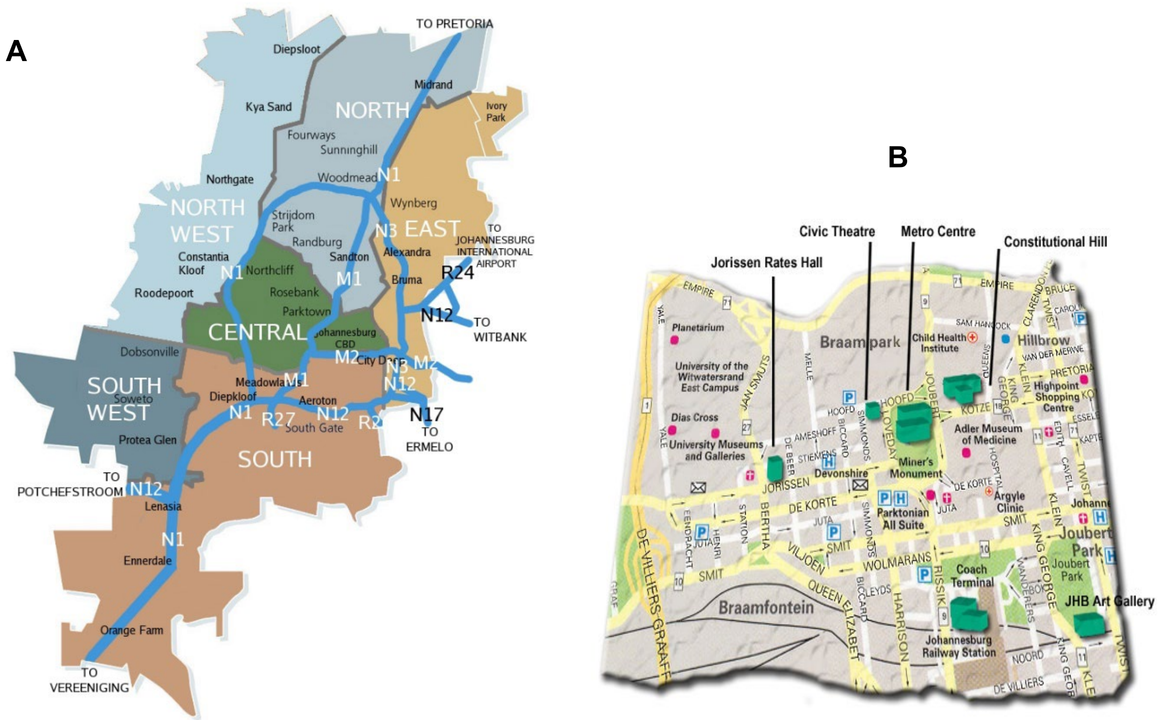

Figure 3.1 Map of the City of Johannesburg (A) and Braamfontein (B)

3.2. Study design

This was a cross sectional study, conducted on 54 formal and 60 informal nail technicians.

3.3. Study population

The study population comprised all nail technicians working in selected nail salons in Johannesburg, and those working in the informal sector in Braamfontein near the Johannesburg CBD, in the period January 2019 to October 2021. Only those whose work entailed nail treatments (applications) exclusively and had worked as nail technicians for at least one year were included in the study population.

3.4. Study sample

The study sample size was computed using G*Power 3.1.9.2 software. Assuming a 10% non-response rate, a sample size of 120 nail technicians was selected, using a power of 80% and a statistical significance of 5%. The sample size calculation took into consideration the comparison of the formal and informal study participants. The calculation used a moderate effect size of 0.48 between the VOC exposures of formal and informal nail technicians. Figure 3.2 is a screenshot of the sample size calculation.

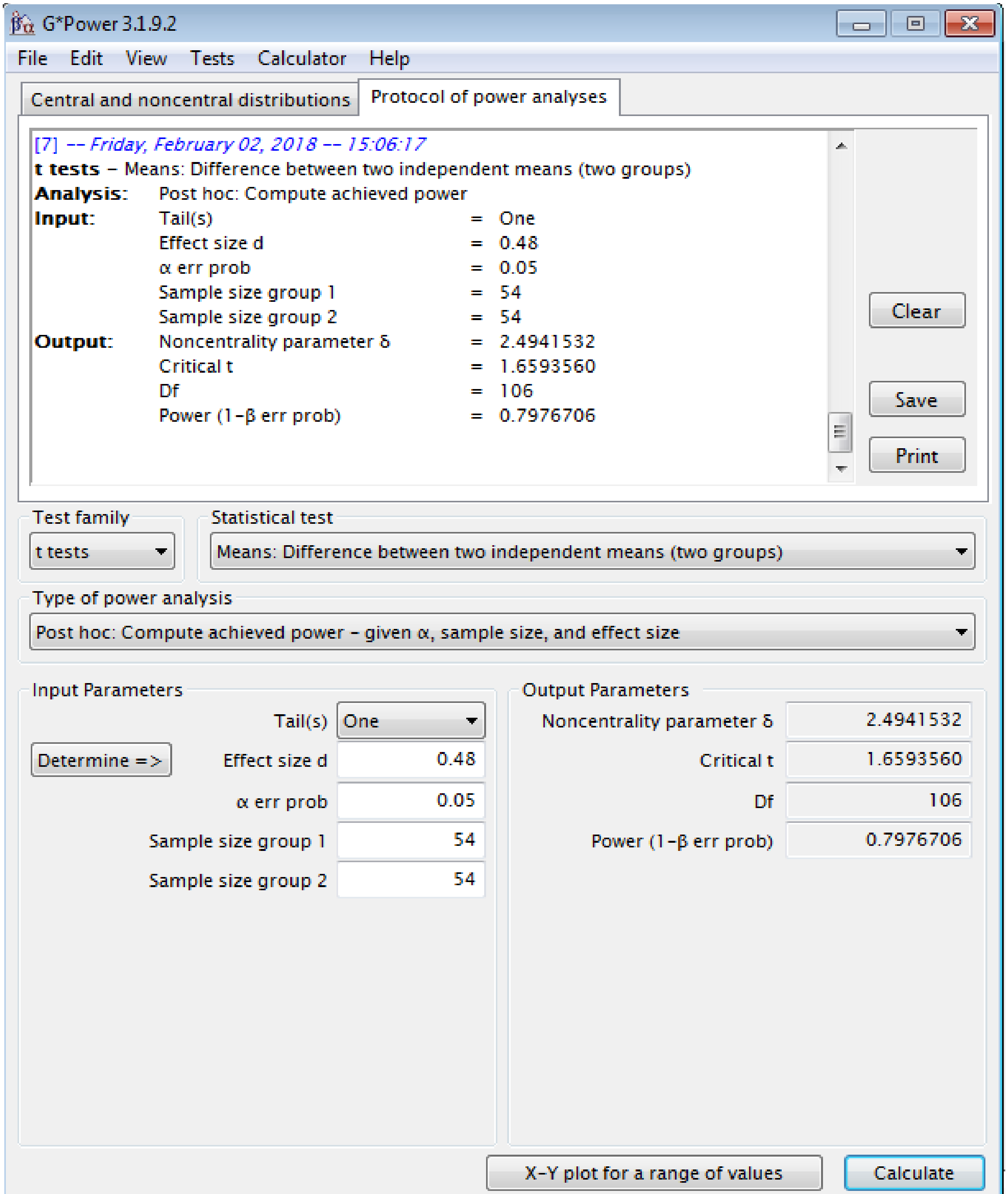

Figure 3.2 Sample calculation using G*Power 3.1.9.2

Convenience sampling was used to select the nail technicians from both the informal and formal nail salons. Of the 120 nail technicians solicited to take part in the study, 114 agreed to participate (54 from the formal nail salons and 60 from the informal nail salons). All 114 participants were included in the 1st phase of the study, which was to administer a questionnaire designed to gather information on sociodemographic characteristics, perceptions of working with nail products, and self-reported symptoms. A subset of 20 formal nail technicians and 20 informal nail technicians was conveniently selected for inclusion in the exposure assessment phase. The two groups were each divided into two groups of 10 for the controlled/expert exposure assessment (CAE) and the self-assessment of exposure (Figure 3.3). Self-assessment of exposure (SAE) is an exposure assessment methodology wherein the worker conducts full-shift unsupervised measurements. They take a more active role in the sampling procedure, collection of contextual information using field data sheets, and selection of measurement days.

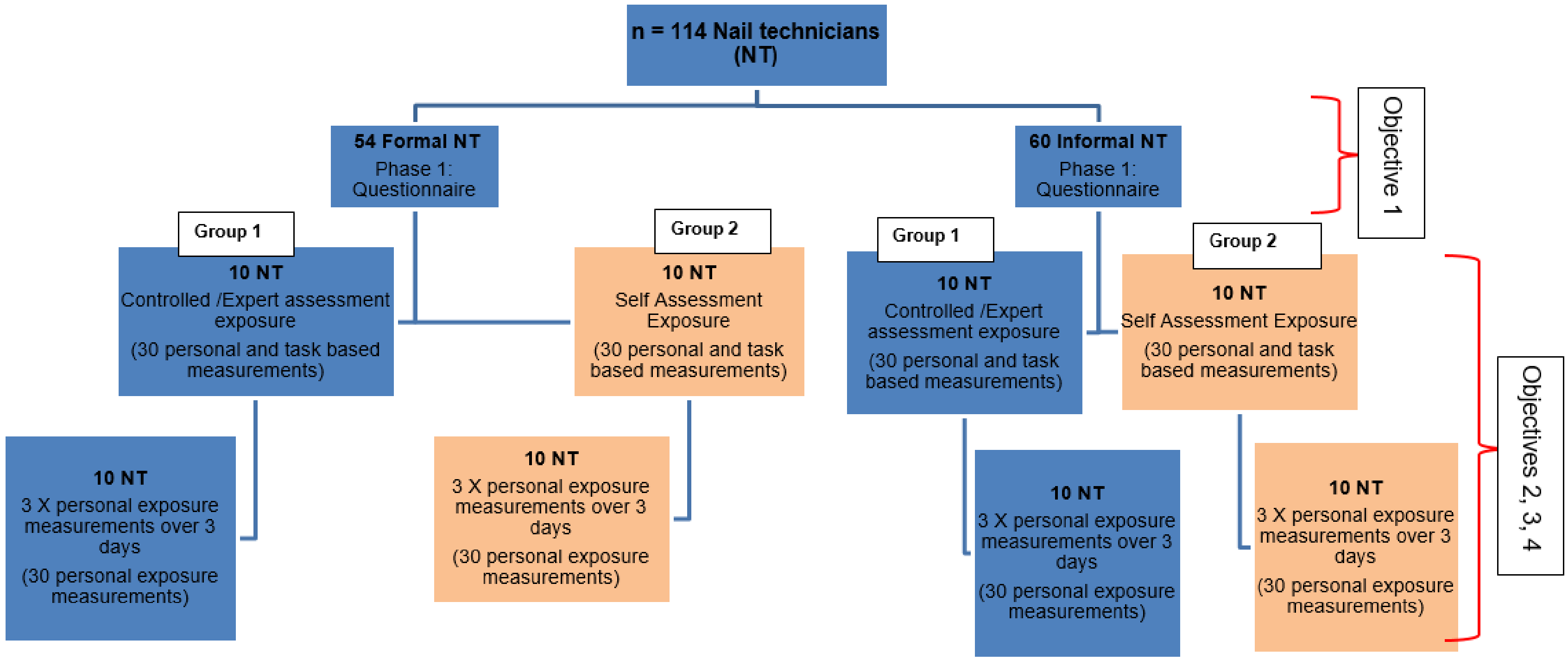

Figure 3.3 Sampling and measurement strategy for the assessment of exposure to volatile organic compounds (VOCs) among formal and informal nail technicians

The study population, sampling, data collection tools, data collection process, and analysis are described in greater detail in the manuscripts related to this study (Brouwer et al., 2023, Keretetse et al., 2022, Keretetse et al., 2023a, Keretetse et al., 2023b). A brief summary of the methods, according to the study objectives is presented in the following sections and outlined in Table 3.1.

Table 3.1 Summary of objectives and statistical analysis

Objective	Study sample size (nail technicians)	Data collection tools	Data analysis
To estimate the prevalence of self-reported symptoms associated with the use of nail products in formal and informal nail salons in Johannesburg, South Africa.	114 (54 formal, 60 informal)	Questionnaire (Appendix 6), Data capture sheet (Appendix 7), Radiello® Passive sampler, SKC UMEx 100 Passive Sampler, MiniRAE 3000, photoionization detector (PID), Laser distance measurer, Indoor Air Quality Meter	Descriptive statistics Descriptive and inferential statistics. Monte Carlo Simulation
To measure the level of exposure to chemicals in nail products used in the formal and informal nail salons.	20 (10 formal, 10 informal) 3 exposure measurements over 3 days (total of 30 samples)	Data capture sheet (Appendix 7), Radiello® Passive sampler, MiniRAE 3000, photoionization detector (PID), Laser distance measurer, Indoor Air Quality Meter	Descriptive and inferential statistics. Monte Carlo Simulation for human health risk assessment
To investigate the feasibility and reliability of self-assessment of exposure as a method of estimating exposure to chemicals used in the formal and informal nail salons	40 (20 formal, 20 informal) for SAE and CAE 3 exposure measurements over 3 days (total of 60 samples)	Data capture sheet (Appendix 7), Radiello® Passive sampler, Laser distance measurer, Indoor Air Quality Meter	Descriptive and inferential statistics.
To investigate the association between respiratory symptoms (chronic and acute) and chemical exposures in formal and informal nail technicians and conduct a probabilistic risk assessment to estimate the carcinogenic and non-carcinogenic risks associated with exposure to volatile organic compounds.	20 (10 formal, 10 informal)	Questionnaire (Appendix 6), Data capture sheet (Appendix 7), Radiello® Passive sampler, SKC UMEx 100 Passive Sampler, MiniRAE 3000, photoionization detector (PID), Laser distance measurer, Indoor Air Quality Meter	Descriptive and inferential statistics. Monte Carlo Simulation for human health risk assessment

3.5. Data Collection Tools

Quantitative data were collected by means of a questionnaire, comprising close-ended questions designed to gather information on sociodemographic characteristics, perceptions of working with nail products, the associated health effects, and self-reported symptoms (acute and chronic). The questions were adopted from existing questionnaires used in other studies (Roelofs et al., 2008, Harris-Roberts et al., 2011, Park et al., 2014) (see Appendix 6).

Personal exposure measurements were performed by means of diffusion or passive sampling in the form of VOCs and formaldehyde badges attached to the participant's collar/lapel. The passive samplers are ideal for measuring low levels of VOCs. They do not require sampling pumps and offer high uptake rates. This results in faster sampling time, greater adsorbent capacity, and, ultimately more reproducible results.

Task-based exposure measurements were carried out using a photoionization detector (PID) to measure peak exposures during specific nail application activities. This device is a standard direct reading instrument that provides real-time information, which is very useful to identify sources of exposure and to associate concentration levels with processes and activities.

A data capture sheet (see Appendix 7) was used to record observations and information such as the time the exposure measurement device was applied, the activities performed by the nail technician during the time of measurement, personal protective equipment (PPE) used and other control measures in place.

3.6. Data Collection

While the details of each data collection procedure, chemical analysis (where applicable) and data analysis are presented in the results chapter of each manuscript (Brouwer et al., 2023, Keretetse et al., 2022, Keretetse et al., 2023a, Keretetse et al., 2023b), a brief outline is presented in this section, with reference to the relevant manuscript.

3.6.1. Phase 1: Administering questionnaires to address objectives 1 and 2

Phase 1 entailed administering the questionnaires to nail technicians (n = 114) from both the formal and informal sectors: 54 formal nail technicians and 60 informal nail technicians. Prior to this, a pilot study was conducted to test the feasibility of conducting a study on formal and informal nail technicians, which included testing the self-developed questionnaire and collecting preliminary data about their knowledge and awareness of health risks associated with exposure to chemicals in nail products, and associated symptoms. The participants of the pilot study were not included in the main PhD study.

The questionnaires for both the pilot and the main PhD study were administered at the nail salons by trained research assistants. The research assistants administered the questionnaire in English before the start of the work day, and/or between clients at the salon where the nail technicians worked. Observations were made about the work practices and the availability/use of exposure control measures during nail applications activities at the nail salons.

3.6.2. Phase 2: Exposure assessment to address objectives 2, 3 and 4

This phase comprised a measurement strategy to assess personal exposure as well as to measure task-specific peak exposure levels of selected VOCs emitted from nail products during specific nail application tasks (see Table 1.1).

a. Task-based peak exposure and personal exposure measurements:

Task-based exposures were measured in the controlled/expert exposure assessment group (Group 1) for both the formal and informal nail technicians by the principal investigator, using a photoionization detector (PID) to measure peak exposures during specific nail application activities. The MiniRAE 3000 PID was used for continuous detection of total VOCs using a 10.6eV lamp (range 0.1 – 15 000 ppm). All the measurements were area measurements, where the sampler was placed near the nail technician's' breathing zone. The direct reading instrument was programmed to log concentrations every minute. Measurements were taken for the full duration of the nail application, covering all the steps involved, in order to detect peak exposures during the tasks that were anticipated to produce high concentrations of VOCs. A similar sampling strategy was used in a study conducted by Goldin et al. (2014), in which they reported significantly higher salon-average total volatile organic compound (TVOC) concentrations in nail salons where the nail technicians performed services such as pedicures, manicures, silk nails, gel nails and acrylic nails, compared to those where services where not performed at the time of measurement.

In addition to the task-based peak exposure measurements, personal 8-hour TWA exposure measurements were conducted on this group by means of diffusion sampling. Three 8-hour personal exposure measurements were taken over a period of three days for each participant; 30 personal exposure measurements in total. The principal investigator attached the passive sampler to the lapel of the participant in order to obtain a sample within the wearer's breathing zone. A data capture sheet (Appendix 7) was used to record information such as the time that the passive sampler was opened and donned, the number and types of nail applications performed, duration of the nail applications performed, PPE used, and other control measures that were in place.

b. Personal exposure measurements using self-assessment of exposure (SAE):
Personal 8-hour TWA exposure measurements were carried out for the remainder of the participants (10 formal and 10 informal nail technicians), which formed Group 2. Measurements in this group were conducted by means of a self-assessment exposure strategy, adopted from studies done by others (Hedmer et al., 2017, Hertsenberg et al., 2007, Pettersson-Strömbäck et al., 2008). All participants in this group performed their own exposure assessment. Each participant conducted three 8-hour personal exposure measurements over a period of three days: 30 personal exposure measurements in total. Participants were given verbal instructions on how to handle the passive samplers and record the required information on a prepared data capture sheet. Participants attached the passive samplers on their own lapels in order to obtain a sample within the breathing zone, similar to the procedure followed in Group 1. The same field sheet as used for Group 1 was applied, where the participants recorded information such as the date and time that the passive sampler was opened and donned, the number and types of nail

applications performed, duration of the nail applications performed, PPE used, etc. Group 2 self-assessed their exposure themselves, while Group 1 was supervised by the principal investigator throughout the duration of sampling period.

Each passive air sampler was sealed and placed in a designated bag to be collected by the research assistants at the end of the working shift. The bags were collected and stored at 4˚C before being transported to the analytical laboratory for analysis. Field blanks were also collected to check for contamination during transport. During this period, correct sample storage procedures were followed. Sample analysis by means of gas chromatography with a flame ionization detector (GC-FID) was conducted by a South African National Accreditation System (SANAS) accredited laboratory.

The layout of each nail salon and the nail technicians' workstations were also noted. Salon dimensions were measured with a laser distance measurer (Laser Measurer Model GLM 80; Bosch). Multiple air quality parameters (CO_2, temperature, and relative humidity) were measured at each salon at the start and the end of the work day - indoor and outdoor (one meter from the entrance). With the permission of the salon managers and the participants, photographs were taken to document observations.

c. Quality assurance:

All the monitoring equipment was calibrated prior to use in this study. The principal investigator performed personal exposure assessments as well as peak-exposure measurements on the participants in Group 1. Participants in Group 2 were trained on how to handle the samplers and record information throughout the sampling period. Proper sample handling and storage procedures were strictly adhered to. Sample analysis was conducted by a SANAS accredited laboratory. Field blanks were collected and analysed to check for contamination during transport.

3.7. Chemical Analysis

Details of the chemical analysis are described in each publication (see Results Chapter and Appendices 1 - 4). In brief, chemical analysis was conducted by a SANAS accredited laboratory. For personal exposure VOC samples, gas chromatography with a flame ionization detector was used to detect all analytes. Based on the literature review, and information obtained from the labels of the products used, and the ingredients list (not always available), the following compounds were quantified: ethanol, acetone, methyl ethyl ketone (MEK), ethyl acetate, benzene, trichloroethylene, methyl methacrylate, ethyl methacrylate, propyl acetate, methyl isobutyl ketone (MIBK), toluene, perchloroethylene, n-butyl acetate, ethyl benzene, xylene, d-limonene, chloroform, 2-propanol, 1-propanol, and white spirits. The limit of detection for all compounds was set at 0.50 µg/ml by the laboratory, to simplify the calculation for all VOCs analysed. For the analysis of formaldehyde, the OSHA 1007 analytical method was followed. Formaldehyde was extracted from the UMEx 100 samplers with 2 mL of high-purity acetonitrile, and samples were analysed using an Infinity High-Pressure Liquid Chromatograph (HPLC).

3.8. Risk Assessment

A probabilistic risk assessment was conducted to estimate the potential risk of formal and informal nail technicians developing adverse health effects from exposure to VOCs emitted from the nail treatments they perform . This risk assessment approach estimates the probabilistic distribution of a risk function by treating some variables as random variables from their respective distributions (Hadei et al., 2018, Dehghani et al., 2021, Cheng et al., 2022, Natarajan et al., 2022, Mahdavi et al., 2023). The non-cancer risk from exposure to selected VOCs (toluene, xylene, methyl methacrylate, 2-propanol, and benzene) and the cancer risk from exposure to benzene and formaldehyde were estimated.

We applied ModelRisk (Vose Software) to simulate the distribution of the risk calculation outputs, i.e. a Hazard quotient (HQ) or a cancer risk (CR) value. The variables used and their distributions are listed in Table 3.2. All of these variables were randomly entered into a Monte Carlo simulation with 1 000 iterations. To identify the parameters that significantly affected the health risk assessment outcome, a sensitivity analysis was conducted. The output of the simulation was presented for the 50^{th}-percentile, and 95^{th}-percentile, a histogram for each outcome, and a sensitivity (tornado) plot.

The equations used to calculate the chronic daily intake (CDI) via inhalation, the HQ and the CR for each of the selected VOCs are described in detail in the manuscript by Keretetse et al. (2023b).

Table 3.2 Variables used for cancer and non-cancer risk assessment among formal and informal nail technicians

Parameter	Definition	Unit	Distribution	Value	Source
C	Concentration of VOC	mg/m^3	Normal	See Table 2 (VOC concentrations)	Measured data (Table 3)
IR (Female)	Inhalation rate	m^3/day	Normal	13.68±1.76 (female)	U.S. EPA (2011)
IR (Male)	Inhalation rate	m^3/day	Normal	17.48±2.81 (male)	U.S. EPA (2011)
WHr (Formal NTs)	Working hours per day	Hour	Normal	8.67±0.95 (formal NTs)	Sampling data (Table 2)
WHr (Informal NTs)	Working hours per day	Hour	Normal	9.22±1.03 (informal NTs)	Sampling data (Table 2)
EF	Exposure frequency	days/year	Triangle	83 (48 – 100)	Questionnaire data
ED	Exposure duration	years	Triangle	30 (25 – 35)	U.S. EPA (2011)
AT (Female)	Average lifetime (life expectancy)	years	Normal	68.4±6.82 (Female)	Statistics South Africa (2021a)
AT (Male)	Average lifetime (life expectancy)	years	Normal	62.4±6.24 (Male)	Statistics South Africa (2021a)
BW (Female)	Body weight	Kg	Normal	67.7±18.58 (Female)	Puoane et al. (2002)
BW (Male)	Body weight	Kg	Normal	66.3±17.62 (Male)	Puoane et al. (2002)
RfC	Inhalation reference concentration	mg/m^3		5 for Toluene	U.S. EPA (2005)
				0.1 for Xylene	U.S. EPA (2003b)
				0.7 for MMA	U.S. EPA (1998)
				0.2 for 2-Propanol	Burleigh-Flayer et al. (1997)
				0.3 for Benzene	U.S. EPA (2003a)
CSF	Cancer slope factor	mg/kg/day		0.029 for Benzene	U.S. EPA (2003a)
				0.045 for Formaldehyde	U.S. EPA (2010)
CDI	Cumulative daily intake	mg/kg.day		output	
CR	Cancer risk	unit less		output	
HQ	Hazard quotient (non-cancer risk)	unit less		output	

MMA, methyl methacrylate; NTs, nail technicians
Values are presented as mean±SD, and median (range)

3.9. Data Analysis

Various types of data analyses, using different statistical software, were applied to the data that were collected. These are described in detail in the papers related to the PhD study (Brouwer et al., 2023, Keretetse et al., 2022, Keretetse et al., 2023a, Keretetse et al., 2023b) and are summarised in Table 3.1. In brief, imputation of data for VOC concentrations below the limit of detection (LOD) was done using Expostats -NDexpo /RoS tool, a web application that implements a rigorous censored data treatment method, the regression on order statistic (Robust ROS) (Lavoue, 2015, Craig et al., 2019). Thirteen VOCs with a detection frequency of ≥ 30% were selected for further analysis from the 20 reported VOCs. As there were variations in both the type and quantity of VOCs in the formal and informal nail salons (some at significantly higher levels than others), calculating the total concentration by summing the concentration of all the VOCs would lead to skewed results. To overcome this, a revised measure of total VOC (TVOC) concentration was estimated, using the selected VOCs. The concentration of each VOC was adjusted according to its evaporation rate in comparison to that of d-limonene, which evaporates at the slowest rate. This allowed for fair comparisons to be made. Self-reported symptoms were categorised into four categories, viz. neurological effects (category A), respiratory effects (category B), eye irritation (category C), and skin irritation (category D) and a symptoms score was calculated. The respiratory additive adverse effect for the VOCs of interest was calculated using the AGCIH additive mixture formula (equation 2) (ACGIH, 2021, Department of Employment and Labour South Africa, 2021).

3.10. Ethical considerations

All ethical principles which include voluntary participation, informed consent, anonymity, confidentiality, maleficence, and beneficence were adhered to throughout the study. Permission to conduct the research in the formal salons was obtained from the relevant authorities (see Appendix 8). Written consent was given by all participants recruited for this study from the formal and informal nail salons (see Appendix 9).

Information about the study was given to the participants during the recruitment phase. The name and details of the principal investigator, purpose of the study, procedures involved, risks, and benefits, and the rights of the participants were explained. Permission to take photographs was requested.

Data were de-identified and a confidential master list was maintained by the principal investigator. This included the names of individuals and companies participating in the research. All hard copies of the data collection sheets were locked in a secure cabinet in the principal investigator's office. All electronic data were password protected and only the principal investigator had access to the data. The study was approved by the University of the Witwatersrand Human Research Ethics Committee (HREC): certificate number M171184 (Appendix 10).

CHAPTER 4: RESULTS

This chapter summarises the findings from the study, which are presented in detail in the four publications that emanated from the research (Appendices 1 – 4).

4.1. Summary of the papers

Awareness of health risks and self-reported symptoms among nail technicians (pilot study)

Citation: Keretetse G, Brouwer D, Nelson G. Evaluating awareness of health risks and self-reported symptoms among nail technicians in Johannesburg, South Africa – a pilot study. Occup Health Southern Afr. 2022; 28(6):223-228 (Appendix 1).

A pilot study was undertaken to test the feasibility of conducting a study on formal and informal nail technicians. A self-developed questionnaire was used to collect preliminary data about nail technicians' knowledge and awareness of health risks associated with exposure to chemicals in nail products, and associated symptoms. Ten formal and 10 informal nail technicians, working in conveniently selected nail salons in Johannesburg, were recruited into the study. The questionnaire was administered to the study participants, and work practices and exposure control measures were observed. The findings are described in a paper published in 2022 in Occupational Health Southern Africa. The pilot study demonstrated that a bigger study was feasible with respect to accessing participants and administering the questionnaire in a clear and understandable manner. The initial questionnaire needed to be revised as the phrasing of some questions was unclear, especially those related to awareness of potential health risks associated with working with nail products. After the pilot study, the tool was refined to include knowledge and awareness about the specific chemical contents of the nail products and the related potential health effects, and a wider range of symptoms and their work-relatedness.

The preliminary data from the pilot study showed that informal nail technicians worked longer hours per week than formal nail technicians (median of 61.5 and 46.5 hours, respectively) and reported more symptoms. This may be due to the flexible nature of their work and undefined working hours. Informal nail technicians were predominantly male, compared to the formal nail salons which employed female nail technicians only. Nail products used by informal nail technicians were mainly from unknown brands bought at the discretion of the nail technicians, whereas the formal nail technicians used known brands purchased through standardized procurement procedures, since they were part of a franchise. None of the nail technicians received training on health and safety aspects related to working with nail products. Formal nail technicians reported receiving training, however, this was not specific to health and safety. They were trained on nail application methods and how to handle and dispose of nail products. Informal nail technicians relied on ‘on-the-job training’.

Pilot studies serve a critical role in assessing the practicability of undertaking large-scale epidemiological studies, along with gathering preliminary data to support the basis for pursuing a bigger investigation. Additionally, they prove instrumental in pre-testing data collection instruments, such as questionnaires and devices. The significance of this small-scale study lies in that it highlighted the nature of the nail technicians' profession and the level of alertness surrounding potential hazards.

Health risk assessment

Citation: Keretetse G, Nelson G, Brouwer, D. Health risk assessment of nail technicians in the formal and informal sector of Johannesburg, South Africa. 2023. Submitted Ann Work Expo Health. (Appendix 2).

In this paper, the outcomes of two of the objectives are addressed, viz. to estimate the prevalence of self-reported symptoms associated with the use of nail products in the formal and informal nail salons, and to investigate the association between respiratory symptoms (chronic and acute) and chemical exposures. A comparison of the sociodemographic characteristics of the study participants showed that the formal sector employed mainly women while the informal sector employed both male and female nail technicians.

Sixty percent of the informal nail technicians reported having experienced health related symptoms, compared to 52% of the formal nail technicians. The informal nail technicians reported more ill health symptoms than the formal nail technicians, with informal male nail technicians reporting the highest number of symptoms than their female counterparts. The main reported acute effects of VOC exposure were headaches, eye irritation, respiratory effects, and skin disorders. All VOC concentrations were below their respective occupational exposure limits, with the exception of formaldehyde (0.21 mg/m^3). The additive exposure threshold for respiratory effects was exceeded in all the informal nail salons. The non-carcinogenic and carcinogenic effects of selected VOCs and formaldehyde were also assessed, using a probabilistic risk assessment approach. The median and 95th percentile non-cancer risk for all nail technicians exceeded the acceptable risk estimate or Hazard Quotient of 1 for xylene, 2-propanol, and benzene. The 95th percentile hazard quotients calculated for xylene, 2-propanol, and benzene were 3.18×10^1, 1.75×10^4, and 3.25, respectively among formal female nail technicians. For the informal male nail technicians, the 95th percentile hazard quotients for xylene, 2-propanol, and benzene were 2.45×10^1, 1.05×10^3, and 4.66, respectively. The HQ was higher for xylene and 2-propanol in the formal female nail technicians and higher for benzene in the formal male nail technicians. The cancer risk values (median and 95th percentile) estimated for benzene and formaldehyde exceeded the US EPA cancer risk level of 1×10^{-6}. The median cancer risk of benzene among informal male nail technicians was 1.96×10^{-3}, while the 95th percentile cancer risk of benzene was 5.47×10^{-3}. The 95th percentile was 5 470 times higher than the acceptable value.

Assessment of VOC exposure among formal and informal nail technicians

Citation: Keretetse G, Nelson G, Brouwer D. Exposure of formal and informal nail technicians to organic solvents found in nail products. Front Public Health. 2023; 11:1147204. doi: 10.3389/fpubh.2023.1147204.

(Appendix 3).

In this paper, the findings from the assessment of VOC exposures and the task-based exposure assessment of different nail applications are presented. Personal passive sampling of VOC concentrations was carried out over three days on 10 of the formal and 10 of the informal nail technicians. There were differences in the nail products used, the types of nail applications performed, the number of clients serviced, and VOC concentrations in the breathing zones of the formal and informal nail technicians. The reported concentrations of 13 VOCs that were comparable and detected at ≥30% detection frequency (DF) were converted into total VOC (TVOC) concentrations, adjusted for their respective emission rates to allow for comparison within and between nail technician categories. Formal nail technicians were exposed to higher but not statistically significant different total volatile organic compounds (TVOC) concentrations than informal nail technicians, with acetone and 2-propanol contributing the most to the TVOC. The formal nail technicians were exposed to significantly higher TWA (8h) TVOC concentrations (geometric mean (GM) 43.8 ppm, geometric standard deviation (GSD) 2.49) than the informal nail technicians (GM 9.87 ppm, GSD 5.13). This may be attributed to the different nail application procedures conducted in the formal nail salons, as well as 'background' emissions from their co-workers - the bystander effect. Methyl methacrylate was detected among informal nail technicians at higher frequencies (89.7%) than the informal nail technicians (3.4%), most likely due to the greater popularity of acrylic nail applications among clients in the informal than the formal sector. Task-based measurements for short-term peak exposures were conducted to provide additional exposure characteristics. Nail applications that included soak-off at the beginning of the nail application process to remove existing nail polish resulted in high TVOC peaks.

This is the first study to compare organic solvent exposures among formal and informal nail technicians and determine task-based peak exposures.

Feasibility and reliability of self-assessment of exposure as a method of determining exposure to chemicals used in formal and informal nail salons.

Citation: Brouwer D, **Keretetse G,** Nelson G. Quantitative self-assessment of exposure to solvents among formal and informal nail technicians in Johannesburg, South Africa. Int J Environ Res Pub Health. 2023; 20:5459. Available from: https://doi.org/10.3390/ijerph20085459 (Appendix 4).

This paper addresses the third objective, which was to compare two methods, self-assessment of exposure (SAE) and controlled exposure assessment (CAE), to determine exposure to chemicals used in the formal and informal nail salons. As part of the SAE approach, 10 formal and 10 informal nail technicians were told how to use a passive sampler and an activity sheet. The data collection was impacted by COVID-19 restrictions, which resulted in a time gap between the SAE and the CAE regime. Business closures and retrenchments also led to difficulty recruiting the same nail technicians from the main study, who participated in the controlled assessment, to participate in the self-assessment regime. For the SAE regime, participants independently conducted their exposure measurements for three consecutive days, after which the samples were collected and transported to the laboratory for chemical analysis. Of the 21 VOCs analysed, 11 VOCs with detection frequency ≥ 30% of the LOD were selected. These were converted into adjusted total VOC (TVOC) concentrations. There were no significant differences in adjusted TVOC concentrations between the assessment regimes, although formal nail technicians were exposed to significantly higher levels. The results suggest that the different exposure assessment regimes did not significantly affect the exposure assessment results. Consequently, the results of both CAE and SAE were pooled, revealing a significant difference in the adjusted TVOC concentrations between both categories. However, based only on the CAE or SAE data, no statistically significant differences between the formal and informal nail technicians were observed. These findings show that the SAE method is effective in expanding an exposure dataset to produce reliable estimates for situations with considerable exposure fluctuations.

CHAPTER 5: DISCUSSION

The chapter presents an integration and discussion of the research findings, as well as an overview of the study's limitations and strengths. The scholarly contributions derived from the study and its potential policy implications are elaborated upon. The discussion concludes with recommendations and suggestions for future research that may address any knowledge gaps stemming from this research.

5.1. Key Findings

The overarching aim of this research was to assess chemical exposures from the use of nail products and describe health effects among nail technicians within the formal and informal sectors of the nail industry in Johannesburg, South Africa. Table 5.1 shows how this aim was achieved through the research objectives and the manuscripts that resulted from them. The high-level findings are also summarised.

Table 5.1 Research objectives and key findings summarised in published and submitted manuscripts

No.	Objective	Title of manuscript	Key findings
1	To estimate the prevalence of self-reported symptoms associated with the use of nail products in formal and informal nail salons in Johannesburg, South Africa.	Evaluating awareness of health risks and self-reported symptoms among nail technicians in Johannesburg, South Africa – a pilot study	Conducting research in this sector is feasible. The questionnaire was revised to elicit more information about nail salon characteristics, work practices, and a wider range of symptoms. The informal sector employs both male and female nail technicians. The informal nail technicians worked longer hours; formal nail technicians serviced more clients. A wider range of products was used in the informal sector. The formal sector uses structured procurement procedures and standard products across their nail salons.
		Health risk assessment of nail technicians in the formal and informal sector of Johannesburg, South Africa.	Self-reported acute symptoms were grouped into categories: neurologic effects, respiratory effects, eye irritation, and skin irritation. Sixty percent (n=36) of the informal nail technicians reported having experienced health-related symptoms, compared to 52% (n= 28) of the formal nail technicians. Informal male nail technicians reported more symptoms (69%) than informal female nail technicians (53%).
2	To measure the level of exposure to chemicals in nail products used in the formal and informal nail salons.	Exposure of formal and informal nail technicians to organic solvents found in nail products.	Formal and informal nail technicians used different nail products, performed different nail applications, serviced different mean numbers of clients, and were exposed to different concentrations of selected VOCs. CO_2 levels were higher in informal than in formal salons. TVOC levels were higher in formal nail salons, due to the bystander effect from multiple nail technicians performing nail applications simultaneously. Acetone concentrations were higher in formal nail salons, due to the soak-off method used. MMA concentrations were higher in informal nail salons - related to more acrylic methods used in the informal than the formal nail salons. High TVOC exposures were measured during acetone soak-offs used to remove existing nail applications.

3	To investigate the feasibility and reliability of self-assessment of exposure as a method of estimating exposure to chemicals used in the formal and informal nail salons.	Quantitative Self-assessment of Exposure to Solvents among Formal and Informal Nail Technicians in Johannesburg, South Africa	Main contributing VOCs: acetone, n-butyl acetate, and 2-propanol in the formal nail salons; EMA and MMA contributed most to TVOCs in the informal nail salons. No significant differences detected in the adjusted TVOCs between the self-assessment of exposure (SAE) and controlled assessment of exposure (CAE) regimes. SAE is feasible to conduct in resource-constrained scenarios and can be used to extend the data set for reliable estimates of exposure. SAE limitations: participants may not collect sufficient supplementary data to support the exposure concentration data.
4	To investigate the association between respiratory symptoms (chronic and acute) and chemical exposures in formal and informal nail technicians and conduct a probabilistic risk assessment to estimate the carcinogenic and non-carcinogenic risks associated with exposure to volatile organic compounds. .	Health risk assessment of nail technicians in the formal and informal sector of Johannesburg, South Africa.	Significant correlations in the informal sector: - age and respiratory effects - sex and neurological effects - working hours and respiratory effects Measured VOCs were not carcinogenic, except for benzene and formaldehyde. Except for formaldehyde, all exposure concentrations were below their respective OELs. Non-cancer risk threshold (HQ=1) for xylene, MMA, 2-propanol, and benzene were exceeded, indicating unacceptable risk for both formal and informal nail technicians. All cancer risk values (95th percentile) were exceeded for benzene and formaldehyde, suggestive of a risk of developing acute and chronic health outcomes from long-term exposure.

5.2. Integrated findings from the study

Nail technicians spend their working days providing nail care services to patrons across different sectors of life. These services range from basic manicures and pedicures, and the application of nail polish to more elaborate and longer-lasting gel and acrylic nail applications. Nail technicians use products that contain a variety of chemicals. The most commonly used nail polishes contain plasticisers, hardeners and preservatives in the form of formaldehyde, dibutyl phthalate (DBP), and toluene - a combination sometimes referred to as the 'toxic trio' (U.S. EPA, 2007). Nail polish remover, which is used to remove previous nail applications, contains acetone as the main ingredient. Liquid and powder acrylic, which are used to create sculptured nails, contain methyl methacrylate, which is banned by the US FDA due to its respiratory sensitising effects. Methyl methacrylate has been replaced with a similar and potentially less toxic substance, ethyl methacrylate. These chemical substances are known to cause adverse health effects.

Working conditions play a role in the exposure of nail technicians to these chemicals and many have reported developing adverse health effects since entering the nail care industry. In this study, formal and informal nail technicians' work conditions and practices were assessed. Exposure to the VOCs emitted from products they use was measured, self-reported acute and chronic health effects were recorded, and estimates of cancer and non-cancer risks were calculated.

5.2.1. Differences between formal and informal nail technicians

In South Africa, formal nail salons are established and licenced businesses that are registered and regulated by the relevant legislative regulations. Informal nail salons are run by individuals who usually operate independently from their homes or small premises. They tend to be unlicensed and unregulated (Statistics South Africa, 2021b, Chen, 2012). The fees charged for the services offered by formal nail salons are usually higher than those offered by informal nail salons.

Several differences were identified between the nail technicians in the formal and informal nail salons (Keretetse et al., 2023a). In this part of the study, it was observed that informal nail salons employed both male and female nail technicians, while the formal sector employs female nail technicians almost exclusively. Those working in the informal sector worked longer hours compared to the formal sector nail technicians. The number of clients serviced also differed between the two groups with the formal nail technicians servicing more clients, even though they worked shorter hours than the informal nail technicians. This can be attributed to the observed practice where two nail technicians work simultaneously on one client, conducting multiple nail applications (Figure 5.1). The task-based measurements showed high peak exposures from such activities where two nail technicians were performing two nail applications on a client. Soak-off and bio sculpture applications were performed on a client's hands by one nail technician, while another nail technician was performing a pedicure on the client's feet at the same time. This saves time but results in higher TVOC concentrations and increased exposure.

Figure 5.1 Simultaneous nail applications performed on a client by two nail technicians

Formal nail salons employ more nail technicians than informal salons, with several working in one nail salon (four to six per shift); informal nail technicians work alone or in pairs, usually in a hair salon. This may have contributed to the difference in the adjusted TVOC concentrations among formal and informal nail technicians. Formal nail technicians had higher adjusted TVOC concentrations than informal nail technicians, although the difference was not significant. This may be due to the background emissions from co-workers in the formal nail salons (the ‘bystander’ effect).

Nail applications performed in nail salons make use of products containing a variety of chemicals known to cause adverse health effects. Informal nail technicians used a wider range of nail products, some of which were unknown brands, than do formal nail technicians. Since the formal nail salons were part of a big beauty brand in South Africa, operating under a franchise model, their work procedures and procurement processes were standardised. The formal nail salons purchased their products from the same suppliers, following the company’s procurement procedures. In contrast, the informal nail technicians worked independently, often as freelancers, leasing a space in a hair salon. This influenced the work practices, procurement procedures, and the types of products they used. The procurement of products in the informal nail salons was at the discretion of the individual nail technicians.

Based on general knowledge and our observations, formal nail salons are more expensive, and are perceived to offer a safer and more satisfactory experience to customers due to their sanitation standards, and the use of higher quality products and known brands. Informal nail salons provide a cheaper option for customers who cannot afford to visit a formal salon, but the health and safety risks may be higher.

Formal nail technicians undergo training to qualify as nail technicians. In the pilot study, although formal nail technicians reported having received training (Keretetse et al., 2022), this focused on nail treatment procedures, and how to handle and dispose of nail products, rather than health and safety aspects of the work. The majority of the informal nail technicians trained while on the job, and their awareness of health risks was based on their individual experiences of working with nail products. Formal training and health and safety training are not a requirement in the informal industry as the industry is not well regulated. Although employers in the informal sector have the same responsibilities as those in the formal sector, regarding protection from exposure to hazards, under the Occupational Health and Safety Act, in practice, the informal sector is less 'regulated' in that there are not enough Department of Employment and Labour inspectors to ensure that informal (and to some degree, even formal) businesses comply with these requirements.

Some of the chemicals found in nail products are aromatics hydrocarbons (toluene, xylenes), aldehydes, esters (ethyl acetate, butyl acetate), acrylates (methyl methacrylate, ethyl methacrylate), ketones (acetone, methyl ethyl ketone), alcohols (ethanol, isopropyl alcohol), plasticisers (dibutyl phthalate, triphenyl phosphate), and terpenes (pinene, limonene, camphor). In our exposure assessment study, a total of 20 VOCs were analysed and 13 showed a detection frequency of ≥30% above the LoD among the formal and informal nail technicians (Keretetse et al., 2023a). These were n-butyl acetate, ethyl acetate, acetone, ethanol, 2-propanol, d-limonene, toluene, ethyl methacrylate, methyl methacrylate, white spirits, propyl acetate, xylene, and benzene. These VOCs are similar to those measured in other studies (Harrichandra et al., 2020, Lamplugh et al., 2019, Zhong et al., 2019). High levels of acetone were measured in both the formal and informal nail salons, similar to what was reported in studies by Park et al. (2014) and Ma et al. (2019). This was expected since acetone is the main ingredient in nail polish removers and is used to remove existing nail polish. An interesting practice of removing existing nail applications was observed among the formal nail technicians. The acetone soak-off method, used mainly by formal nail technicians, involved immersing clients' hands in an acetone hot bath. This method is similar to the 'bain-marie technique', where a bowl filled with acetone is placed in a larger bowl filled with hot water to heat it up gently. This speeds up the nail application removal process, thereby reducing the duration of the nail application process. Informal nail technicians used a different method, which involves applying cotton wool pads soaked in acetone to the client's nails and wrapping them in tin foil. This method takes longer but uses less acetone than the hot bath method. This explains the higher acetone concentration measured among the formal nail technicians than the informal nail technicians.

Formal nail technicians were exposed to n-butyl acetate and 2-propanol at 100% and 96.6% detection frequency, respectively. This was more than the detection frequency measured among informal nail technicians and may be attributed to the high frequency of nail polish applications conducted in formal nail salons, using nail products containing n-butyl acetate and 2-propanol. Formal nail technicians were also observed to apply disinfectant, of which 2-propanol is a constituent, on their clients' hands, their workstations, and their nail application tools before the start of any nail application.

The detection frequency for MMA was found to be higher for informal nail technicians than for formal nail technicians. This was attributed to the popularity of acrylic nail applications among clients in informal nail salons. It may also be evident of the continued use of products in the informal sector that contain MMA.

Nail technicians reported experiencing ill health symptoms since they started working in the industry. Similar results were reported in a study by Ma et al. (2019) where nail technicians reported health problems that emerged or worsened after they started working in the nail salon industry. Self-reported symptoms included headaches, light headedness, and irritation of the nose, eyes, throat and skin.

A number of observational studies have compared nail technicians to office workers as controls (Lteif et al., 2020, Ma et al., 2019, Park et al., 2014) in which nail salon workers reported more symptoms than the control groups. Results from our health risk assessment (Keretetse et al., 2023b) showed that 60% (n = 36) of the formal nail technicians reported experiencing ill-health symptoms compared to 52% (n = 28) of the formal nail technicians. All nail technicians' median and 95th percentile non-cancer risks exceeded the acceptable risk of 1 for xylene, 2-propanol, and benzene. The cancer risk estimates (median and 95th percentile) for benzene and formaldehyde exceeded the US

EPA cancer risk threshold of 1 x 10^{-6}. This suggests that the nail technicians are at risk of developing both acute and chronic health effects from long-term low level exposure to VOCs.

Formaldehyde, a known human carcinogen (U.S. EPA, 2010, IARC, 2006) and one of the 'toxic trio', can still be found as an ingredient in some nail polishes and nail hardeners (Zhong et al., 2019, OSHA, 2017), but can also be emitted from other sources such as building materials (Dodson et al., 2017, Huang et al., 2019, Liu et al., 2022). In 2022, Huang and colleagues conducted a study on the impact of residential building materials on ambient air levels of formaldehyde in mainland China. Their research showed that indoor sources, particularly residential building materials in urban regions, were responsible for a considerable amount of ambient formaldehyde (Huang et al., 2022). Several building materials incorporate formaldehyde as a crucial element, including phenol formaldehyde (PF) or phenolic resin, urea formaldehyde, and melamine resin (Healthy Building Network, 2008). In 1962, formaldehyde was identified as a potential pollutant indoors and linked to the emission of artificial boards that contained urea formaldehyde (UF) adhesives. Among wood-based building materials, furniture, decorative materials, and laminate wood flooring are the prime sources of indoor formaldehyde (Huang et al., 2019, Salthammer et al., 2010). Other sources of formaldehyde are products used for hairdressing activities (Hadei et al., 2018, Pexe et al., 2019, Zhong et al., 2019). A study on hairdressing salons in Taipei reported formaldehyde concentrations ranging from 12.40 to 1.04 x 10^3 μg/m^3; the maximum level was above the OSHA permissible exposure limit (PEL) (Chang et al., 2018). In our study, formaldehyde concentrations for the formal nail salons were below the LoD, therefore only measurements for the informal nail salons were analysed. Concentration levels for the informal nail salons exceeded both the South African 8-hour TWA and the ACGIH TLV for formaldehyde. Many of the informal nail salons in this study included hairdressing activities, which may explain the high concentrations of formaldehyde measured.

5.3. Strengths and limitations

The research study had several strengths and limitations which are summarised below.

First, we used convenience sampling to select study participants. This sampling strategy is limited in that inferences and generalisations to other nail technicians cannot be made, i.e. external validity is compromised. However, the nail salons assessed in the formal sector were all part of a franchise and were thus very similar in terms of the layout, work organisation, and products used. Despite the sampling strategy limitation, we have shown that exposures to VOCs in the nail industry might be high enough to potentially cause adverse health effects.

Second, for ventilation measurements, the salon room occupancy was not monitored as the number of patrons visiting the salons varied throughout the day. Therefore, the contribution of room occupancy to the CO_2 concentrations could not be determined. However, the measured increase in CO_2 during the day for informal nail salons indicated the lack of adequate ventilation.

Third, the PID sensitivity in characterising individual VOCs limited the findings to reporting only TVOCs and not characterising the individual VOCs detected during the task-specific measurements. The selection of VOCs was based on the literature review. Limited information was obtained from the labels of the products used and the ingredients list (infrequently listed). Safety data sheets on products were not available from the informal nail salons.

Another limitation was the different time periods when the SAE and CAE measurement regimes were conducted. This was due to delays in recruiting participants into the study and the resumption of data collection due to several challenges experienced (see preface for details). Reasons for the delays included the initial unwillingness of some nail salon owners to take part in the research, student protests, and xenophobic unrests near some of the study sites. The COVID-19 pandemic and subsequent nationwide lockdown also had an impact.

The SAE measurement regime took place during the winter period (June 2021) when temperatures were relatively low, and the CAE measurement were recorded during the warmer months (October 2021). This is expected to influence the exposure levels since lower temperatures decrease volatility. Nonetheless, the concentrations were elevated due to a lack of ventilation due to doors being kept closed during the winter period. The time gap between the SAE in the informal sector and the CAE sampling campaigns resulted in the samples of the SAE in the informal sector being analysed separately from the others. This affected the decision about which particular VOCs to include in the analysis.

In addition, the lack of contextual information regarding the nail technician's activities from some of the SAE exposure data, which is necessary to understand exposure results, was missing. The lack of information regarding the association between the participant's behaviour and exposure limits the use of this assessment method as a citizen science tool. Citizen science refers to the practice of public participation and collaboration in scientific research to enhance scientific knowledge.

The COVID-19 pandemic and the national lockdown restrictions led to a reduction in the number of clients per day, because of the required reduced room occupancy and social distancing protocols. The informal sector was hit the hardest by the Pandemic as fewer clients visited the nail salons, leading to reduced income. Most nail technicians/ salon owners struggled to pay rent and their employees because of reduced economic activities; subsequently, some nail salons closed. The formal sector had more resources and thus a greater ability to withstand the economic shock of the Pandemic, because of higher levels of social security and government interventions. Individuals in the informal economy, without social security, faced a higher risk of falling into poverty. This could explain the large variation in VOC concentrations between the formal and informal sectors.

Additional limitations include that 1) no routes of entry other than inhalation were considered in this study, e.g. the dermal route; 2) the internal dose could not be determined since we did not carry out any biological monitoring; 3) the symptoms were self-reported and no clinical assessments were done; 4) the time difference between administering of the questionnaires and taking the measurements may have influenced the association between the reported symptoms and VOC exposures; 5) the formal nail technicians were from a single franchise group, and this might impact the representability since this group might differ somewhat from other franchise groups in products used and work practices.

Nevertheless, this is the first study to assess exposure to VOCs in the often-overlooked informal sector and to compare these exposures with those in the formal sector of the beauty industry. This study has generated personal breathing zone concentration data for nail salon workers, including the informal sector, which is always difficult to approach for research. Differences were found between the two sectors relating to salon characteristics, working conditions, type of nail applications conducted, and self-reported symptoms. The combination of shift measurements and task-based measurements is particularly useful for providing an exposure profile in this under-researched group of workers and identifying high-exposure tasks for targeted interventions.

5.4. Scholarly contribution of the PhD study

This is the first study to assess VOC exposure in the often-overlooked informal sector in comparison to the formal sector of the nail industry in South Africa. Salon characteristics, work practices, nail technicians' sociodemographic characteristics, exposure data, and acute and chronic health effects were evaluated and compared between the two sectors of the nail industry.

Exposure to VOCs were compared between nail technicians in the formal and informal sectors of the nail industry in South Africa. Personal breathing zone concentrations were measured for selected VOCs, based on the literature and product information. Task-based exposure measurements for different nail applications were also taken, to identify when peak exposures occur during the nail application processes (Figure 5.2). If peak exposures can be identified, then targeted interventions can be developed and implement.

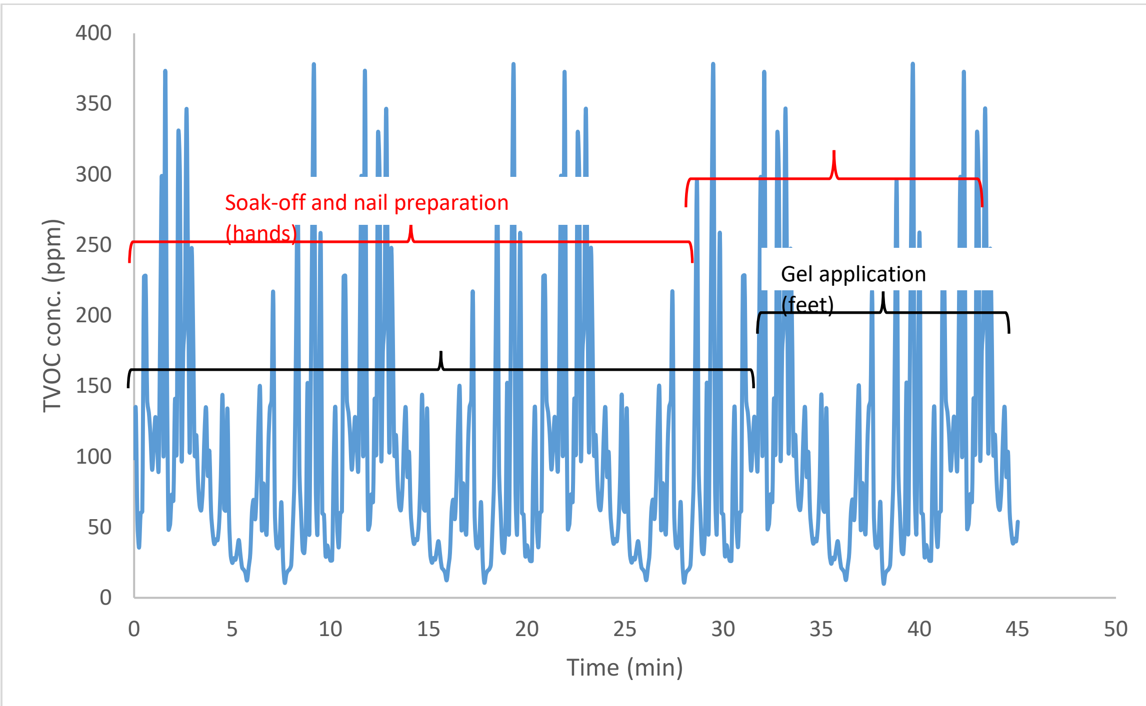

Figure 5.2 Time profile of peak exposure to volatile organic solvents (ppm) of soak off and bio sculpture gel application on hands and pedicure, simultaneously, in the formal nail salons

A number of VOC concentrations were below the limit of detection (LoD) from the personal breathing zones A convenient method of analysing censored data, i.e. data reported as below the limit of detection (LoD), to substitute a common value (e.g. LoD/2 or LoD/√2) for values below the LoD and proceed with the 'usual' statistical analysis. However, the substitution of concentrations below the LoD with LoD/2 or LoD/√2 has been shown to potentially result in substantial bias when the proportion of censored data is large (Hornung and Reed, 1990, Jin et al., 2011). In this study, the imputation of VOC concentrations below the LoD was conducted using Expostats -NDexpo /RoS tool (Lavoue, 2015, Craig et al., 2019), a web application that implements a rigorous censored data treatment method - the regression on order statistic (Robust ROS) - as described by Helsel (2005). This approach is based on fitting detected values to a lognormal distribution and then predicting a replacement value for each ‘non-detect’ as a function of the fitted distribution, and its rank among the detected values.

The feasibility of the self-assessment of exposure (SAE) method as a cost-effective way of collecting exposure data in resource and time constrained situations was evaluated. We found no significant difference in the adjusted TVOC concentrations between the two assessment regimes (SAE and CAE), indicating that the SAE approach is feasible for assessing exposure and can be useful to extend the sample size of a study to provide reliable estimates, especially when the concentration variation is large.

Although the measured VOC concentrations were below their respective occupational exposure limits, with the exception of formaldehyde, the non-cancer risk limit values were exceeded for some of the VOCs, viz. xylene, 2-propanol and benzene. The US EPA cancer risk threshold (1×10^{-6}, i.e., 1 in a million) was exceeded for benzene and formaldehyde. This indicates that there is a risk of developing acute and chronic health effects even from low-level exposure. We adopted a probabilistic risk assessment approach, which estimates the probabilistic distribution of a risk function by treating some variables as random variables drawn from their respective distributions. Probabilistic risk assessment provides a more realistic and comprehensive understanding of risks than deterministic risk assessment, which assumes that all variables are certain and fixed. Deterministic risk assessments provide a single point estimate of risk at a site of concern, while probabilistic risk assessment methods generate a range of values from probability distribution functions (Bruce et al., 2007, U.S. EPA, 2022).

5.5. Policy impact of the research

The collective findings of this research showed that there are distinct differences between the formal and informal sectors of the nail industry. These findings bring attention to the often overlooked informal sector, and create awareness of potential hazards among nail salon owners and the nail technicians. Studies of this nature are useful for developing intervention strategies to minimise exposure, such as informed decision-making with regard to the procurement of nail products, and the adoption of safe work practices to reduce emissions from harmful chemicals among nail salon workers and their clients.

The findings suggest that there is a need for increased/improved regulation and oversight of the nail industry, particularly with respect to the hazardous chemicals commonly found in nail products. Methyl methacrylate was detected in informal nail salons. This substance was banned in 1974 by the US FDA due to its respiratory sensitising effects. Although the measured concentrations of MMA were below the 8-hour time-weighted occupational exposure limit, the mean concentration averaged over 24 hours resulted in an exceedance of the MMA reference concentration of 0.7 mg/m^3. For the informal male nail technicians, MMA had the highest median and 95th percentile estimated HQ values at 2.09 x 10^3 and 8.73 x 10^3, respectively. The findings also inform policy development to help regulate these industries and ensure worker health and safety. To reduce the risk of exposure, even at these low levels, considerations should be made to ban the use of MMA in nail products in South Africa, due to the severe health effects from exposure. Stricter regulatory requirements should be put in place regarding the labelling of cosmetic products in accordance with the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) and Department of Employment and Labour South Africa (2021) requirements. Ingredients of the nail products should be clearly labelled and visible. The products should also be accompanied by safety data sheets.

5.6. Recommendations

5.6.1. Recommendations for the nail industry

Despite the hazardous nature of the chemicals used in the nail care industry, the use of control measures to minimize exposure has been neglected. Other industries have established hazardous chemical substances control programmes in the form of ventilation and PPE for workers who are exposed to some of the chemicals that are used in nail products (Alaves et al., 2013). Following the hierarchy of controls, substitution of hazardous chemicals in nail products with less hazardous chemicals should be considered. More permanent forms of controls, such as engineering controls (e.g. installing local exhaust and dilution ventilation) would reduce the air concentrations of emissions from nail products. Examples of such ventilation systems are ceiling exhausts to the outside of the building, and downdraft tables with outside exhausts. Researchers from the National Institute for Occupational Safety and Health (NIOSH) in the US have developed a ventilation table that protects nail technicians from breathing air contaminated by hazardous chemical substances in nail products (NIOSH, 2014). Special administrative controls such as safer work practices, job rotation and provision of PPE can be implemented to protect workers from exposure (Alaves et al., 2013).

The following are specific recommendations, according to the hierarchy of controls, for the nail salon industry to address to reduce the health risks of exposure of nail technicians to the chemicals emitted from nail products they use daily.

- Substitute products containing hazardous ingredients with those containing less hazardous ingredients; for example, ban products that contain the 'toxic trio' (toluene, formaldehyde, and dibutyl phthalate) and label new products 'toxic-trio' free. However, care should be taken to avoid having one toxic chemical being replaced by another potentially toxic chemical, a practice known as "regrettable substitution".

- Inspect the product label and safety data sheets (SDS) or information sheet and avoid products containing MMA as one of the ingredients.

- The application of the "soak-off" should be reconsidered; the time saving advantage should be weighed against the risks of high acetone concentrations and product use.

- Nail salon owners should investigate the practicality of installing local ventilation systems in the form of portable LEV systems or ventilated tables. These operate by way of extracting contaminated air away from the nail technician and the clients. Alternatively, a semi-enclosure, using a transparent panel, could be used to avoid direct contact with the vapours emitted from the products.

- Where mechanical ventilation is not possible, general ventilation can be improved by opening doors and windows to allow the flow of fresh air. However, careful consideration should be made to ensure that the airflow is in a direction away from the nail technician and client.
- Used cotton wool pads soaked with products should be disposed of in refuse bins with self-closing lids; alternatively, these should be immediately placed in sealed bags after use, before disposing of them.
- Excess products should not be kept at workstations. Use only the quantities required to perform the nail application service.
- Product manufacturers and suppliers should provide salon owners with safety data sheets (SDSs) for the products they supply. This is a requirement according to sub regulation 14A of the Regulations for Hazardous Chemical Agents (Department of Employment and Labour South Africa, 2021).
- Safety data sheets should be made available to all nail technicians.
- Training should be provided to all nail technicians on the contents of the SDS as per regulation 3 (Information, instruction and training) of the Regulations for Hazardous Chemical Agents (Department of Employment and Labour South Africa, 2021). The training should include information on the hazardous ingredients in the products, how exposure can occur, health and safety risks that may result from using the products, how to access the relevant SDSs, and steps to take to safely use the products, including what to do in case of accidental exposure. Language and literacy level of the nail technicians should be considered when providing training.
- Provide nail technicians with appropriate PPE in the form of N95 respirators for use during buffing and filing of nails and acrylic sculptured nails as these protect against particulate matter, dust, and germs. However, these respirators will not protect again vapours and gases.

Interventions developed for the nail salon industry should take into account the availability and time commitment that nail technicians may need to put in, over and above their current demanding work schedules. Training interventions can be supplemented with brief information brochures or posters that promote safe and healthy work practices. Nail technicians, particularly those in the informal sector, should be encouraged to access free basic health care and health education at public health facilities. Periodic campaigns should be investigated where services such as health education, treatment of common health problems, and occupational health and safety can be provided at the workplace. The above interventions should be applied with input from the nail technicians to encourage uptake and maximum participation.

5.6.2. Recommendations for future research

There is a need for additional research to address the research gaps and limitations that arose from this study. Research should be conducted to investigate the incidence of chronic health effects through longitudinal cohort studies associated with exposure to VOCs and other vapours and dusts emitted during the course of their work.

The personal breathing zone concentrations of selected VOCs, based on information from the literature and available product labels, were reported in this thesis. However, the chemical content of nail products could not be ascertained. Studies should be conducted to identify the chemicals in nail products and link them to specific nail applications and the measured exposures in nail salons. This will inform policy with regard to the identification of hazardous chemical ingredients and the regulation of specific chemicals and possible banning of their use in nail products.

Given the sensitivity issues of the PID, simultaneous task-based exposure measurements should be collected and used to characterise the PID peak exposure data.

Poorly completed field data sheets from the SAE measurement regime resulted in a lack of contextual information to fully understand the exposure data. This can be addressed by employing the use of direct reading devices or wearable low-cost sensors, which may provide not only pollutants exposure estimates but also complementary information to assist in interpreting the results.

Since most informal nail salons were located within hairdressing salons, confounding exposures should also be investigated, as well as the role of other potential sources of the measured VOCs, e.g. formaldehyde, which is an ingredient in hair straightening products. A comparative study should be conducted in nail salons with hairdressing activities and those without.

Further studies should investigate other possible routes of entry of chemicals into the human body, such as dermal exposure assessments. Biological monitoring to identify appropriate biomarkers of exposure should also be investigated to determine the internal dose.

The recommended exposure control measures should be implemented and tested. Laboratory studies are useful to get a first estimate of the efficacy, followed by evaluation of the effectiveness when implemented in real world practice.

Multi-Criteria Decision Analysis (MCDA) should be conducted to identify and compare potential cost-effective interventions and determine their suitability for use in formal and informal nail salons. The following criteria can be used to determine the appropriateness of the intervention: effectiveness in reducing worker exposure to hazardous chemical substances, the feasibility of implementation, acceptability by the worker and client (the intervention should not be cumbersome and hinder the worker's task), and cost. This should follow the hierarchy of controls, from substitution of the health hazard, to engineering controls in the form of extraction or dilution ventilation, to administrative controls such as reducing exposure time, and using PPE.

CHAPTER 6: CONCLUSION

This study revealed the potential exposures faced by formal and informal workers in the beauty industry. We demonstrated differences in the VOCs emitted from the nail products utilised, the type of nail applications executed, and the number of clients serviced by the formal and informal nail technicians. These variables contributed to the measured VOC breathing-zone concentrations, with formal nail technicians experiencing higher TVOC concentrations due to specific acetone 'soak off' techniques used and 'background' emissions from colleagues. Although no significant differences in adjusted TVOC-concentrations were observed between the controlled assessment of exposure (CAE) and self-assessment of exposure (SAE) regimes, in both sectors, significantly higher exposures were recorded for the formal nail technicians. Our findings suggest that applying the SAE approach is feasible in the informal nail sector, and can extend the exposure dataset to include reliable estimates in scenarios with substantial exposure variations.

Informal nail technicians reported more adverse health symptoms than the formal nail technicians. This highlights the health and safety concerns for this sector of the nail industry particularly. Although the exposure levels were below the recommended occupational limits for the selected VOCs (apart from formaldehyde in informal nail technicians), the study findings suggest that nail technicians have a risk of developing carcinogenic and non-carcinogenic health outcomes from long-term low-level exposure to VOCs.

This study is significant because it sheds light on the characteristics of the nail technicians' occupation, highlighting the differences between the formal and informal sectors of the nail industry. The findings suggest that there is a need for a systematic approach to developing effective exposure control measures. Importantly, increased regulation and oversight of the nail industry is recommended, particularly with respect to the hazardous chemicals commonly found in nail products.

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APPENDICES

APPENDICES

Appendix 1

Keretetse G, Brouwer D, Nelson G. Evaluating awareness of health risks and self-reported symptoms among nail technicians in Johannesburg, South Africa – a pilot study. Occup Health Southern Afr. 2022; 28(6):223-228.

Evaluating awareness of health risks and self-reported symptoms among nail technicians in Johannesburg, South Africa – a pilot study

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ABSTRACT

Background: The professional nailcare industry is expanding rapidly in South Africa. Nail treatment involves the use of solvents and acrylates. Exposure to these chemicals is associated with skin, eye, and respiratory tract irritation, and neurological and reproductive health effects.

Objective: To test the feasibility of conducting a study on formal and informal nail technicians, which included testing a self-developed questionnaire, and to collect preliminary data about their knowledge and awareness of health risks associated with exposure to chemicals in nail products, and associated symptoms.

Methods: A self-developed questionnaire was administered to 10 formal and 10 informal nail technicians working in conveniently selected nail salons in Johannesburg. Work practices and exposure control measures were observed. Demographic characteristics, working conditions, awareness of health risks, and self-reported symptoms in the two groups are presented as frequency distributions.

Results: Poor phrasing was identified in some of the questions. Participants provided the correct terminology to describe nail services. The revised questionnaire comprised 39 questions. Seven of the informal nail technicians were male while all the formal nail technicians were female. Informal nail technicians worked longer hours per week than formal nail technicians (median of 61.5 and 46.5 hours, respectively) and reported more symptoms. Informal nail technicians used a wider range of nail products than formal nail technicians and used some unknown brands. Although all participants indicated that they were aware of health risks associated with nail products, only four of the formal nail technicians and one informal nail technician reported receiving training (although not specific to health and safety). Informal nail technicians reported using personal protective equipment (PPE); however, this practice was inconsistent, and they used the incorrect PPE.

Conclusions: We showed that conducting a larger study in nail technicians is feasible. The questionnaire was revised to include more information about the chemical content of nail products, a wider range of symptoms, the frequency of their occurrence, and the work-relatedness nature of the self-reported symptoms. A knowledge gap was identified among nail technicians relating to risks associated with exposure to chemicals in nail products. The questionnaire was refined to assess more accurately nail technicians' understanding of exposure and awareness of health risks associated with chemicals in nail products.

INTRODUCTION

Professional nailcare is a rapidly expanding industry which has seen tremendous growth globally.[1-6] South Africa has also experienced growth in the nailcare industry, in both the formal and informal sectors.[7] While some research has been conducted in the formal sector,[8] little is known about nail salons in the informal sector.

The 15th International Conference of Labour Statistics (ICLS) defined the informal sector as *"non-registration of the enterprise in terms of national legislation such as taxation or other commercial legislation; non-registration of employees of the enterprise in terms of labour laws; or small size of the enterprise in terms of the numbers of people employed"*.[9] Statistics South Africa defines informal work as *"economic activity which takes place without a registered value-added tax (VAT) number"*, and the informal sector as *"those businesses that are non-registered"*.[10]

Nailcare establishments, including those in South Africa, offer nailcare services only, or as part of a comprehensive cosmetics business.[11] The treatment of nails ranges from simple buffing, to basic manicures, to the application of sculptured artificial nails.[12,13] The chemicals in all treatments of natural nails and the application of artificial nails are associated with potential adverse health effects. These include solvents, such as acetone, ethyl acetate, and n-butyl acetate. Additionally, artificial nail applications use acrylic polymers and monomers,[14] which may pose risks to the health of both the nail technicians applying the products and their clients.

One of the main chemical monomers found in acrylic nail products is methyl methacrylate (MMA), a chemical that was banned by the United States Food and Drug Administration (US-FDA) in 1974 due to its skin sensitisation properties, which are associated with allergic contact dermatitis.[15,16] Exposure to MMA causes eye, skin, and respiratory tract irritation, and is associated with asthma.[17] Methyl methacrylate has been replaced with a similar chemical, ethyl methacrylate (EMA), which is considered, in the United States of America (USA) and several other countries, to have lower toxicity.[14] However, some countries, such as South Africa, and certain states in the USA continue to use nail products that contain MMA as they are cheaper than those containing EMA.[18] Consequently, there are pockets of unregulated workers and small industries where nail products containing MMA are still used.[17,19,20]

Acetone and butyl acetate (contained in nail polish removers) may lead to headaches, dizziness and eye, skin and throat irritation.[2,21] Some nail polishes contain toluene, formaldehyde, and dibutyl phthalate (DBP) – a combination referred to as the 'toxic trio'.[22,23] Toluene can affect the central nervous system (CNS) and cause reproductive harm.[24] The CNS effects include headache, light-headedness, dizziness, confusion, nausea, impaired judgment, and blurred vision.[19,25,26] The reproductive effects, such as risk for pregnancy complications, as well as developmental delays and neurobehavioral difficulties, have been reported to be higher in the offspring of women who have been exposed to high concentrations of toluene during pregnancy.[27] Formaldehyde has been classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC), based on the findings of nasopharyngeal cancer and leukaemia studies.[28] Exposure to DBP has been linked to reproductive problems such as birth defects and negative developmental and reproductive system effects.[19,22,29,30] There are many other harmful chemicals used in nailcare products. Park, et al. (2014), in a study on the comparison between nail technicians and office workers, showed that a significantly higher proportion of nail technicians were exposed to airborne acetone, toluene, butyl acetate, and MMA reported respiratory, neurologic, eye, skin, and musculoskeletal complaints.[17] Symptoms such as headaches and light-headedness have been reported to worsen after starting work in the nail salon industry.[3]

Internationally, several studies have investigated the characteristics, work conditions, and self-reported symptoms in nail technicians, and knowledge of health and safety regulations and products used.[21,31,32] Studies in Korea, the United Kingdom (UK), Vietnam, and the USA have reported musculoskeletal disorders, respiratory symptoms, skin problems, and headaches.[17,21,31] Only one study has been conducted in South Africa, on the respiratory and dermal exposures to volatile organic compounds (VOCs) from products used in nail salons.[8] The authors reported that nail technicians were exposed to VOCs at levels below the recommended occupational exposure limits specified by the Regulations for Hazardous Chemical Agents framed under the South African Occupational Health and Safety Act (Act No. 83 of 1995).[33] The study assessed only VOC exposures, in the formal sector. Worker characteristics and health effects associated with exposure were not included.

The aim of this pilot study was to test the feasibility of conducting a study on nail technicians in Johannesburg, South Africa in the formal and informal sectors. The study included testing a self-developed questionnaire, and collecting preliminary data about the nail technicians' knowledge and awareness of health risks associated with exposure to chemicals in nail products, and associated symptoms.

METHODS

Formal nail salons were defined as those that are licensed and registered as part of a franchise. Informal nail salons comprised those not licensed or registered with any formal enterprise or establishment.

Ten nail technicians, working in six conveniently selected nail salons from the three largest nail salon franchise companies in Johannesburg, and 10 working in conveniently selected informal nail salons in Braamfontein, near the Johannesburg central business district (CBD), were invited to participate.

Data were collected, using a self-developed questionnaire, designed to gather information on sociodemographic characteristics, perceptions of working with nail products, knowledge of associated health effects, and self-reported symptoms. The questions were adapted from questionnaires used in other studies on nail technicians.[17,21,31] Those studies incorporated standardised and validated questions on respiratory health from the American Thoracic Society questionnaire and the Protocol for the European Community Respiratory Health Survey,[34] while the skin-related questions were based on the Nordic Occupational Skin Questionnaire – NOSQ 2002.[35] Questions adopted from these studies addressed careers, average number of clients seen per day, type and duration of nail services, knowledge of health and safety issues in the workplace, self-reported health problems, and measures taken to protect their health. Open-ended questions were added to elicit responses about their experiences and their work environments.

Table 1. Characteristics of formal and informal nail technicians

Characteristic	Category	Formal sector (n = 10)		Informal sector (n = 10)	
		n	%	n	%
Sex	Male	0	-	7	70.0
	Female	10	100.0	3	30.0
Age (years)	< 30	4	40.0	8	80.0
	30–40	4	40.0	2	20.0
	> 40	2	20.0	0	-
Work history (years)	< 1	0	-	1	10.0
	1–5	5	50.0	7	70.0
	6–9	3	30.0	2	20.0
	≥ 10	2	20.0	0	-
Working hours per day	8–9	7	70.0	6	60.0
	10–11	3	30.0	1	10.0
	≥ 11	0	-	3	30.0
Number of clients per day	4–6	3	30.0	4	40.0
	7–9	5	50.0	3	30.0
	≥ 10	2	20.0	3	30.0
Smoking	Yes	1	10.0	2	20.0
	No	9	90.0	8	80.0

The first draft questionnaire, comprising 35 questions, was assessed by experienced researchers to address face validity. Feedback highlighted issues such as redundant questions, and clarity and phrasing of some questions. The questionnaire was modified for the pilot study.

The questionnaire was paper-based and was administered in English by the researcher before the start of the work day, or between clients at the salon where the nail technicians worked. The participants' responses were audio-recorded to assess their initial reactions to the questions and the need for clarification. The questionnaire was timed and, at the end of administering it, the participants were asked how they perceived both the study and the questionnaire. Work practices and exposure control measures during nail treatments were observed and documented; photographs were taken.

The study was approved by the University of the Witwatersrand Human Research Ethics Committee (Medical), certificate number M151194.

Data analysis

All data from the questionnaires were captured in Microsoft Excel, checked for missing data, and cleaned for any data entry errors. Data analysis was performed using STATA iC15.0. Sociodemographic characteristics, awareness of health effects, and self-reported symptoms were described using frequencies and proportions for categorical variables. Means and standard deviations, and medians and ranges, were used to describe continuous variables. The self-reported symptoms were categorised into four categories: respiratory effects, neurological effects, skin irritation, and eye irritation. Since the sample size was small (< 30), Cronbach's alpha could not be calculated to determine the internal consistency of the tool.[36]

RESULTS

Characteristics of study participants

Most of the informal nail technicians in the study were men (n = 7, 70.0%), while all those in the formal sector were women (Table 1). Nail technicians in the formal nail salons were older and had worked for longer in the nail industry than those in the informal nail salons.

Informal nail technicians worked for more hours per week (median 61.5 (56–72)) than formal nail technicians (median 46.5 (45–54)). The mean number of clients serviced per day, however, was similar for both groups, viz. 7.4 ± 2.2 and 7.4 ± 2.1, respectively.

Face validity of the questionnaire

The piloted questionnaire initially comprised 35 questions. The researchers who assessed the content found the questions to be inclusive and able to capture the purpose of the pilot study; however, they recommended rewording some of the questions for clarity. Seven questions were thus modified. The question about the perception of how harmful the nail products are was preceded by two questions asking the participant's knowledge about health effects related to the chemicals found in nail products (*"Do you know if the chemicals in nail products may cause any health effects?"*; and *"If yes, please list the health effects"*). Two questions were deemed very similar and were merged: *"Do the symptoms experienced when working with nail products improve or worsen while at work?"* and *"Do the symptoms experienced when working with nail products improve while away from work?"* The resultant question was *"Do the symptoms experienced while working with nail products get better when away from work?"*.

The pilot study participants expressed that they were comfortable with the questions asked and felt that the study was important to address health- and safety-related issues in the nailcare industry. In some instances, they corrected the terminology used to describe the services they offer. For example, the phrase 'nail treatment', used to describe the services offered, was replaced with 'nail application'. The question, *"Do you know the chemical content of the nail products that you use?"* was often confused with knowledge about the nail products themselves. This question was therefore preceded by two additional questions: *"What type of nail products do you use?"* and *"Have you ever read the label of these nail products?"*, to give clarity to the question on chemical content. Three nail technicians asked for clarity about the question, *"How harmful do you think these nail products are?"* as they assumed that it referred to the potential harm caused to the client and not themselves. After modifying seven questions, merging two, and adding four new ones, the questionnaire – to be used in a larger study – comprised 39 questions (see Supplementary Appendix 1). The estimated time taken to complete the questionnaire was 45 minutes; the actual time was around 35 minutes, including the time taken to explain the study and for participants to sign the consent form.

Health risk awareness, working conditions and self-reported symptoms

The formal nail salons were part of the three big franchises in South Africa and operated under a franchise model, with several nail salons employing more than one nail technician per salon. The informal nail technicians worked independently, often as freelancers, leasing a space in a hair salon. This influenced the work practices, procurement procedures, and the types of products they used. The formal nail salons purchased their products from common suppliers, following the company's procurement procedures, while procurement of products in the informal nail salons was at the discretion of the individual nail technicians.

All the study participants knew the names of the products and their intended use, but none were familiar with the chemical contents (Table 2). Information related to the use and handling of nail products

Table 2. Knowledge and awareness about nail products among formal and informal nail technicians

Item	Formal sector (n = 10)		Informal sector (n = 10)	
	n	%	n	%
Knowledge about products	10	100.0	10	100.0
Knowledge about chemical content of products	0	-	0	-
Health and safety information	4	40.0	1	10.0
Awareness of health risks	7	70.0	10	100.0
Use of PPE	5	50.0	10	100.0

PPE: personal protective equipment

was reportedly provided to four (40.0%) of the formal nail technicians during their training, while only one (10.0%) of the informal nail technicians indicated they had received training. Some participants reported that the training did not incorporate health and safety aspects of their work, but focused on nail application methods, and the use and disposal of nail products. Seven (70.0%) nail technicians in the formal and all those in the informal (n = 10, 100.0%) nail salons said that they were aware of the health risks associated with working with nail products. This was informed mainly by their experiences of working with nail products every day and the ill-health symptoms that they experienced.

Although the participants reported using masks as personal protective equipment (PPE), this was at their discretion. The masks were dust masks and did not provide protection against the chemical compounds to which they were exposed. Dust masks protect only against exposure to particulates, whereas nail technicians are exposed to VOCs. They wore the dust masks when using nail products that they perceived to emit toxic chemicals, e.g. when applying acrylic nail products or using acetone. These tasks involve the use of nail products that have a distinct odour.

Figure 1 shows the acute health-related symptoms reported by nail technicians since they started working in the nail industry. These included sneezing, coughing, flu-like symptoms, sinusitis, dizziness, headache, red/itchy skin, and red eyes. Informal nail technicians reported more health-related symptoms than formal nail technicians.

The nail technicians reported many similar symptoms – most were related to sinuses and the upper respiratory tract. The symptoms most frequently reported by the informal nail technicians were respiratory effects (n = 6), neurological effects (n = 5), and skin and eye irritation (n = 2). The formal nail technicians reported respiratory effects (n = 3), neurological effects (n = 1), and skin irritation (n = 1).

Some of these symptoms were perceived to be caused by specific nail products or related to specific nail treatments:

> *"It (runny nose) only occurs during the day when using the product (monomer). It starts as I am busy with a client and when I am done it stops."* (formal nail technician)

The symptoms were also perceived to be related to dust generated when performing a specific task during a nail application:

> *"Around the chest, there is (are) always complications there, even now you can hear my voice is not coming out clearly. I think there is a congestion of dust. Especially when we file the nails it brings out dust."* (informal nail technician)

DISCUSSION

The primary objective of this study was to test the feasibility of conducting a study on formal and informal nail technicians, which included testing a self-developed questionnaire, and collecting preliminary data about their knowledge and awareness of health risks associated with exposure to chemicals in nail products, and associated symptoms. We demonstrated that such a study is feasible with respect to accessing participants and administering the questionnaire in a clear and understandable manner. The initial questionnaire needed to be revised as the phrasing of some questions was unclear, especially those related to awareness of potential health risks associated with working with nail products. After conducting the pilot study, the tool was further refined to include knowledge and awareness about the specific chemical contents of the nail products and the related potential health effects, and a wider range of symptoms and their work-relatedness.

Information about room size, ventilation, and confounding factors such as chemicals emitted from other activities in the

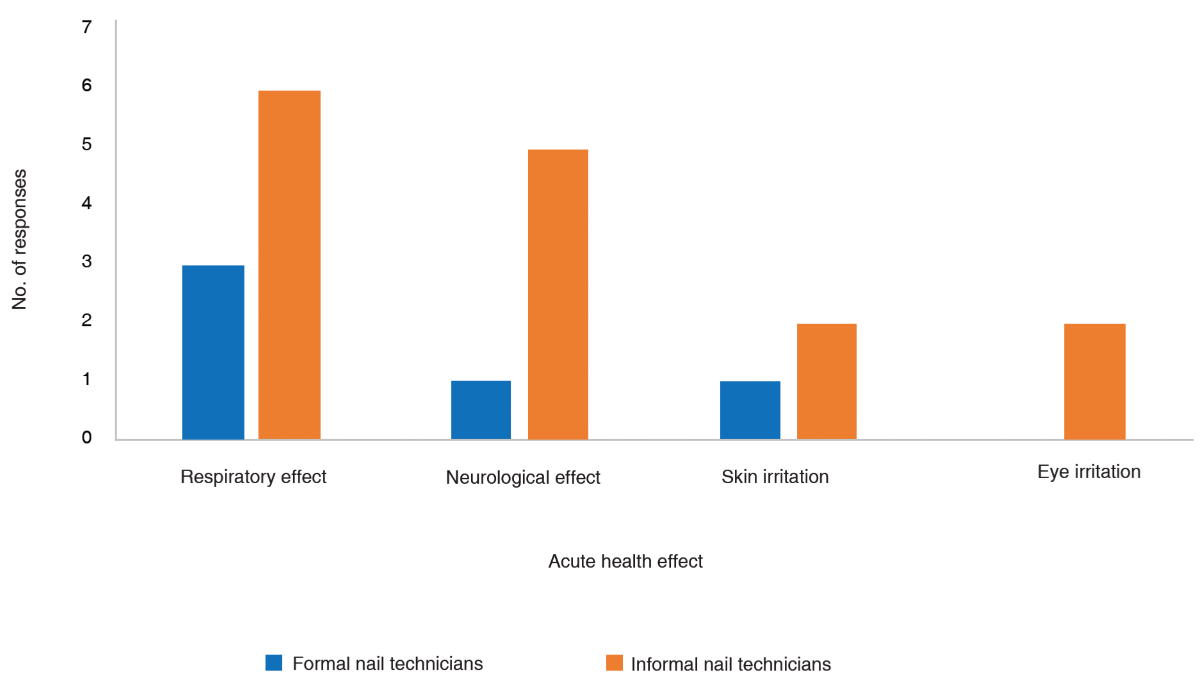

Figure 1. Self-reported ill-health symptoms among formal and informal nail technicians

nail salon (e.g. hairdressing) will be included in a larger study, where exposures to specific chemicals used in nail treatments will be assessed.

Although this was a pilot study, with very few participants, there were some interesting findings, the validity of which will need to be tested in a larger study. The informal nail technicians worked for more hours and reported more symptoms than the formal nail technicians. This might be attributed to the flexible nature of their work as they do not have defined working hours, which is common in the formal sector.

In the pilot study, the informal nail technicians were predominantly male, which was unexpected. Formal nail technicians were older and had worked in the industry for longer periods. This may be due to the formalised structure of the sector and the security that the job provides in terms of regular working hours and set salaries.[37]

The results from the pilot study also suggested that there are some similarities between the two groups. Nail technicians in both sectors could easily identify the nail products and their intended use but did not know their chemical contents or the related potential health effects of exposure to them. The formal nail technicians reported having received training; however, the training focused on nail treatment procedures, and how to handle and dispose of nail products, rather than the health and safety aspects of their work. The majority of the informal nail technicians relied on training while on the job, and their awareness of health risks was based on their individual experiences of working with nail products. Formal training and health and safety training is not a requirement in the informal industry due to the industry not being regulated. A study on nail technicians from a mixture of rural and urban areas in the UK, published in 2011, reported that the majority of the participating nail technicians (99%) had received training that included aspects of health and safety, and most were aware of the Control of Substances Hazardous to Health (COSHH) regulations and risk assessments.[31] Nail salons in the UK are more formalised and most nail technicians undergo training by their employers or colleges in order to qualify as nail technicians.

Although awareness of health risks was high in both groups, differences were noted in the reporting of PPE use. All informal nail technicians reported using PPE, compared to 50% of the formal nail technicians. However, PPE use was at their discretion, and they wore masks only when performing tasks they perceived to be emitting toxic chemicals, based on the distinct odours. This was both reported and observed. This practice was misinformed as the nail technicians were not knowledgeable about the chemical contents of the nail products or their associated health effects. The choice of PPE was also inappropriate as they used dust masks that only protect against exposure to particulate matter and not VOCs. A study conducted on Vietnamese-American nail salon workers reported similar findings of inappropriate PPE usage, where disposable surgical masks were used.[21] These types of masks are designed for infection control and do not reduce exposure to chemical vapours.

This was a pilot study on a small number of participants; thus, inferences and generalisations cannot be made. However, the preliminary findings suggest that there is a potential for identifying behaviours and practices that are unique to the industry, and differences between the formal and informal sectors.

CONCLUSION

Pilot studies are important for testing the feasibility of conducting large epidemiological studies and collecting preliminary data to support the justification for undertaking a larger study. They are also useful for pre-testing data-collection tools, such as questionnaires and devices. This small pilot study drew attention to the nature of the work of nail technicians and levels of awareness of potential health risks. A comprehensive data-collection tool has been developed for use in the assessment of nail technicians' exposure to, and awareness of health risks associated with, chemicals in nail products, for use in a larger study.

Larger studies are needed to quantify the exposure to chemicals that are associated with adverse health symptoms, and to identify the long-term health effects of these exposures in both the formal and informal nail sectors. Such studies are imperative to ensure the health and safety of vulnerable groups, such as informal nail technicians, due to the nature of their work and the lack of regulation. The findings from such studies can influence policy development to ensure the protection of the health of both workers and patrons in this industry.

KEY MESSAGES

1. Pilot studies provide insight regarding the feasibility of conducting a study and provide preliminary data.
2. Nail technicians in the formal and informal sectors of the beauty industry differ with regard to working hours, number of clients, and types of products.
3. A larger study on nail technicians will determine chemical exposure assessment and the relationship with symptoms; and health risk awareness.

DECLARATION

The authors declare that this is their own work; all the sources used in this paper have been duly acknowledged and there are no conflicts of interest.

AUTHOR CONTRIBUTIONS

Conception and design of the study: GK, DB, GN
Data acquisition: GK
Data analysis: GK
Interpretation of the data: GK, GN, DB
Drafting of the paper: GK
Critical revision of the paper: DB, GN, GK

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Appendix 2

Keretetse G, Nelson G, Brouwer, D. Health risk assessment of nail technicians in the formal and informal sector of Johannesburg, South Africa. Submitted to Ann of Work Expo Health (addressing reviewers' comments).

Health risk assessment of nail technicians in the formal and informal sectors of Johannesburg, South Africa

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Abstract

Exposure to volatile organic compounds (VOCs) emitted from nail salon activities presents a risk of acute and chronic health effects to nail technicians. This study aimed to estimate the prevalence of self-reported symptoms associated with the use of nail products, and to assess the non-carcinogenic and carcinogenic effects of selected VOCs among formal and informal nail technicians in Johannesburg, South Africa, using a probabilistic risk assessment approach. A questionnaire was administered to 54 formal and 60 informal nail technicians to elicit information on sociodemographic characteristics, work conditions, and self-reported symptoms. Passive sampling was used to measure 60 personal breathing zone concentrations of 20 nail technicians over a period of three consecutive days, for selected VOCs. In addition, 29 passive samples for formaldehyde were collected in the informal sector. The findings showed that the formal sector employs mainly females while the informal sector employs both male and female nail technicians. With the exception of formaldehyde, all VOC concentrations were below their respective occupational exposure limits. Sixty percent of the informal nail technicians reported having experienced health-related symptoms, compared to 52% of the formal nail technicians. All nail technicians' median and 95th percentile non-cancer risks exceeded the acceptable risk of 1 for xylene, 2-propanol, and benzene. The cancer risk estimates (medians and 95th percentiles) for benzene and formaldehyde exceeded the US EPA cancer risk threshold of 1×10^{-6}. These findings indicate that nail technicians are a risk of developing acute and chronic health effects from long-term low level-exposure to VOCs.

Keywords: volatile organic compounds, formaldehyde, self-reported symptoms, probabilistic risk assessment, Monte Carlo simulation

1. Introduction

Nail technicians are exposed to volatile organic compound (VOCs) that are emitted from nail products. Exposure is associated with the type and duration of nail applications, products used, working conditions, and number of clients serviced, among other factors. Nail services include basic manicures and pedicures, and nail polish, ultraviolet gel, acrylic nail, and artificial nail applications. A variety of products that contain a cocktail of chemical ingredients are used for different purposes throughout each nail application. The chemicals include solvents such as aromatics hydrocarbons (toluene, ethyl benzene, xylene), aldehydes (formaldehyde), esters (ethyl acetate, butyl acetate, vinyl acetate, methyl methacrylate (MMA), ethyl methacrylate (EMA)), ketones (acetone and methyl ethyl ketone), alcohols (ethanol, isopropyl alcohol, and n-butyl alcohol), plasticizers (dibutyl phthalate, triphenyl phosphate), and turpentines (pinene, limonene, camphor, menthol) (Park et al., 2014, Ceballos et al., 2019, Craig et al., 2019). All treatments involve the use of acetone for the removal of existing nail polish, gel, and acrylic and artificial nails. Nail polish contains a number of chemicals such as lacquer, plasticizers, gloss, and hardeners. Some nail polishes may contain harmful substances commonly referred to as the 'toxic trio' (OSHA, 2017, Young et al., 2018), viz. toluene, dibutyl phthalate (DBP) and formaldehyde. Acrylic nails are made by combining the polymer (a powder) and monomer liquid to form a paste. The monomer is made of methyl methacrylate (MMA), a chemical substance that was banned in the US and other countries by the Food and Drug Administration due to its sensitizing properties (U.S. FDA, 2013). Although MMA was replaced by ethyl methacrylate (EMA), studies have reported the presence of MMA in nail salons (Harris-Roberts et al., 2011, Quach et al., 2011, Alaves et al., 2013, Grešner et al., 2015, Lamplugh et al., 2019, Zhong et al., 2019, Lteif et al., 2020) in several countries. Some nail polish brands have added labels reporting the exclusion of certain toxic ingredients such as lead (Young et al., 2018, Ceballos et al., 2021), and the 'toxic trio', however, some of these substances, e.g. toluene, are still found in nail salons (Lamplugh et al., 2019, Harrichandra et al., 2020).

Salon characteristics, e.g. location, room volume, and ventilation, also play a role in the levels of VOC concentrations. Studies have reported higher emissions of VOCs from nail salons with no ventilation than those with ventilation (Pavilonis et al., 2018, Harrichandra et al., 2020). Goldin et al. (2014) measured total VOC (TVOC) concentrations, particulate matter 2.5 (PM2.5), and carbon dioxide in nail salons in Boston, US, and found that nail services that were being performed (e.g., pedicure, manicure, silk nails, gel nails, acrylic nails, waxing and airbrushing), increased air pollutant concentrations, and ventilation improved indoor air quality. Salon activities were reported to be the source of VOCs due to the high inside-to-outside ratio of VOC concentrations measured in a study conducted in Iran and published in 2018 (Hadei et al., 2018). Hadei et al. (2018) found significant relationships between the concentrations of some compounds (benzene, toluene, ethylbenzene, and formaldehyde) and the number of treatments; effective ventilation reduced exposure concentrations.

Nail technicians have reported symptoms such as headaches, lightheadedness, irritation of the eyes, skin, and respiratory system, and allergic sensitization (Quach et al., 2008, Roelofs et al., 2008, Reutman et al., 2009, Harris-Roberts et al., 2011, Quach et al., 2011, Lamplugh et al., 2019). In other studies, nail technicians reported more health symptoms than office workers (Harris-Roberts et al., 2011, Park et al., 2014, Lteif et al., 2020, Tran et al., 2020). In a study by Ma et al. (2019), nail technicians reported experiencing symptoms since they started working in the nail industry, and that the symptoms worsened when at work. In a qualitative study by Dang et al. (2021), nail technicians identified health issues that they perceived to be directly related to workplace exposures, which included symptoms experienced due to contact with nail products, and poor ergonomics.

Although acute health effects related to chemical exposures in the nail care industry have been studied there are only a few studies on the long-term effects of VOCs from nail products (Hadei et al., 2018, Lamplugh et al., 2019, Tran et al., 2022). Benzene, toluene, ethylbenzene, and xylene are known to cause adverse health effects such as cancer and neurological effects. Benzene has been confirmed to be carcinogenic to humans (Group 1) by the International Agency for Research on Cancer (IARC) and a known human carcinogen (Group A) by the US Environmental Protection Agency (EPA) (IARC, 2018, U.S. EPA, 2003b). Formaldehyde has been classified as a probable carcinogen (Group B1) by the EPA's Integrated Risk Information System (IRIS), and as a human carcinogen (Group 1) by the IARC (IARC, 2006, U.S. EPA, 2010).

To investigate potential differences in both exposure and self-reported symptoms, we conducted a study, comparing these issues in formal and informal nail technicians. We also assessed the non-carcinogenic and carcinogenic effects of selected VOCs, using a probabilistic risk assessment approach.

2. Material and methods

2.1. Study area and study design

This cross-sectional study was conducted in the City of Johannesburg, South Africa. The study participants comprised 60 nail technicians working in 60 conveniently selected informal nail salons in the Braamfontein area near the Johannesburg Central Business District, and 54 nail technicians working in 14 conveniently selected formal nail salons located in the Northern suburbs of Johannesburg. The formal nail salons were licensed and registered as part of a large franchise. Informal nail salons are not licensed or formally registered with any enterprise or establishment (Keretetse et al., 2022). The nail salons offered basic nail services, including manicures and pedicures, and nail polish, gel and acrylic applications. The informal nail salons were nested in hair salons opening to the roadside, while the formal nail salons were located either in a shopping centre/strip mall with the entrance opening to a carpark, or inside a shopping mall with a central walkway where retail stores face one another. The room volume of the formal nail salons was almost twice that of the informal nail salons, with informal nail salons relying predominantly on natural ventilation through open doors (there were no windows). Some of the formal nail salons were equipped with mechanical ventilation in the form of heating, ventilation and cooling (HVAC) systems. None of the participating salons had local extraction ventilation (LEV) systems. Further details about the nail technicians and the nail salons are described in a previously published paper (Keretetse et al., 2023).

The nail salons were visited, and the study was explained to the nail technicians. Ethical approval was received from the University of the Witwatersrand Human Research Ethics Committee (HREC): certificate number M171184.

2.2. Questionnaires

An interviewer-administered questionnaire, designed to collect data on sociodemographic characteristics, work experience, work practices, services offered, working hours, and health symptoms within the last four weeks, was administered to all participants. The questions were adapted from questionnaires used in other studies on nail technicians (Harris-Roberts et al., 2011, Park et al., 2014, Roelofs et al., 2008), and were piloted on 20 nail technicians (10 formal and 10 informal) (Keretetse et al., 2022). The participants of the pilot did not take part in the main study. Research assistants administered the questionnaire in English before the start of the workday, and/or between serving clients at the salon where the nail technicians worked.

2.3. Personal exposure assessment and chemical analysis

Personal breathing zone concentration measurements were conducted on a subset of the participants. A sample of 20 participants (10 formal and 10 informal nail technicians) was conveniently selected from the 114 nail technicians to participate in the exposure assessment phase.

Personal breathing zone samples were collected by means of diffusion/passive sampling (Radiello® Passive sampler, Sigma Aldrich, Kempton Park, South Africa) for VOCs measurements, while formaldehyde measurements were taken using SKC UMEx 100 Passive Sampler (UMEx 100, SKC, Kempton Park, South Africa). The researcher removed the passive sampler from the storage tube and attached it to the lapel of the participant. Measurements covered at least 80% of the work shift, over a period of three consecutive days, for each nail technician. This resulted in a total of 60 personal exposure measurements in the formal (n = 30) and informal (n = 30) nail salons. However, one informal study participant did not present for work on the third day of the assessment, and all measured VOCs for one formal participant were below the limit of detection (LoD) for day 3 of the assessment. The latter scenario may have been a result of mishandling of the sampling device during the measurement period. Consequently, two samples were excluded from the analysis, resulting in a sample size of 58 (29 in each group). Field blanks were also collected to check for contamination during transport. At the end of the sampling period, the Radiello® passive sampler was detached from the participant's lapel, placed in the glass tube, capped, and labeled. The UMex 100 passive samplers' covers were closed and the samplers were placed back into the manufacturer-supplied aluminized bags, sealed, and labeled. All passive samplers were stored at < 5°C until the time of analysis.

2.4. Chemical analysis

Details of the chemical analysis have been published elsewhere (Keretetse et al. (2023). In brief, chemical analysis was conducted by a SANAS accredited laboratory. Following extraction of the sorbent tubes in 2 mL CS_2, gas chromatography with a flame ionization detector was used to quantify the concentrations of VOCs. Chromatographic separation was performed using a DB-624 column (0.25 mm ID, 30 m length, 1.4 µm film thickness) for quantification, and a DB-WAX column (0.25 mm ID, 30 m length, 1.5 µm film thickness) for verification, with a split injection of 3 µL and split flow of 20 ml/min. The carrier gas was nitrogen at a constant pressure of 5 psi. The injector temperature was 220°C and the detector temperature was 200°C. The MSD ChemStation macro program extracted peak areas, adjusted for internal standards, and transferred the data to a Microsoft Excel spreadsheet. The average concentration over the exposure period was calculated from the mass of the analyte found on the cartridge and the reported duration of sampling.

For the analysis of formaldehyde, the OSHA 1007 analytical method was followed. Formaldehyde was extracted from the UMEX 100 samplers with 2 mL of high-purity acetonitrile, using a Waters extraction manifold operated at 457 mmHg. Extracted samples were then diluted to 5mL with additional acetonitrile. Samples were analysed using an Infinity High-Pressure Liquid Chromatograph (HPLC) system equipped with a Phenomenex Luna 5 µm C18 100A (250 x 4.6 mm). The diode array detector was operated at 360 nm. Formaldehyde concentrations were calculated using standard calibration curves and the total volume of air sampled (Hadei et al., 2018). A field blank, stored alongside the formaldehyde samples, was used for blank correction.

Based on the literature review and the information obtained from the product labels, as well as Safety Data Sheets (SDS), 20 VOCs were analysed. To simplify the calculation of the average concentration, the LoD for all VOCs was set at 0.50 µg/ml, and the average lowest concentration value of the samples was set at 0.01 mg/m^3. The LoD for formaldehyde was 0.1 µg per sample.

2.5. Risk assessment

A risk assessment was conducted to estimate the potential risk of exposure to VOCs among formal and informal nail technicians resulting from the nail treatments they perform. The cancer risk from exposure to benzene and formaldehyde and the non-cancer risk from exposure to five selected VOCs (toluene, xylene, methyl methacrylate, 2-propanol, and benzene) were estimated. A number of studies have used the deterministic approach, which considers a point estimate of the worst-case scenario (Masekameni et al., 2018, Lamplugh et al., 2019, Khajeh Hoseini et al., 2022). We adopted a probabilistic risk assessment approach, which estimates the probabilistic distribution of a risk function by treating some variables as random variables drawn from their respective distributions (Hadei et al., 2018, Dehghani et al., 2021, Cheng et al., 2022, Natarajan et al., 2022, Mahdavi et al., 2023).

The following equation was used to calculate the chronic daily intake via inhalation for each of the selected VOCs:

$$CDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

where *CDI* is the chronic daily intake by inhalation (mg/kg BW.day), *C* is the pollutant concentration (mg/m^3), *IR* is the inhalation rate (m^3/24 h), *E* is the exposure frequency (day/year), *ED* is the exposure duration (year), *BW* is the body weight (kg), and *AT* is the average lifetime or the time period over which the dose is averaged (year).

For non-carcinogenic pollutants, the hazard quotient (HQ) was used to estimate the risk. An HQ greater than one was regarded as the pollutant having the potential to cause adverse health effects, whereas HQ values less than one indicates that adverse effects are not likely to occur, and thus can be considered to have negligible risk.

The calculation for HQ was:

$$HQ = \frac{CDI}{RfC} X \frac{BW}{IR_{wd}} \quad (2)$$

where *CDI* is the chronic daily intake by inhalation (mg/kg.day) as calculated in equation 1, *RfC* is the reference concentration (mg/m^3) obtained from the USEPA IRIS, *BW* is the body weight (kg), and IR_{wd} is the inhalation rate per workday (m^3/workday), which is the IR_{24h} * working hours (WHr)/24 h.

Cancer risk for carcinogenic compounds was calculated by the following equation:

$$CR = CDI \; X \; CSF \tag{3}$$

where *CDI* is the chronic daily intake by inhalation (mg/kg.day) as calculated in equation 1, and *CSF* is the cancer slope factor (1/(mg/kg.day)) for the pollutant of interest.

It should be noted that the values of some of the variables were specific to the South African context and differentiated by sex, whereas others were retrieved from the EPA Exposure Factors Handbook. Table 1 lists the parameters associated with health risk assessment used and their respective sources.

2.6. Probabilistic assessment and sensitivity analysis

To address the variability for each parameter in the risk assessment, a probabilistic approach was used. We applied ModelRisk (Vose Software) to simulate the distribution of the risk calculation outputs, i.e. HQ or CR values. The variables used and their distributions are listed in Table 1. All variables were randomly entered into a Monte Carlo simulation with 1 000 iterations. To identify the parameters that significantly affected the health risk assessment outcome, a sensitivity analysis was conducted. The outputs of the simulation are presented using the 50th-percentile, and 95th percentile values, and a histogram and a sensitivity (tornado) plot are presented for each outcome.

Table 1 Variables used for cancer and non-cancer risk assessments among formal and informal nail technicians.

Parameter	Definition	Unit	Distribution	Value	Source
C	Concentration of VOC	mg/m^3	Normal	See Table 2 (VOC concentrations)	Measured data (Table 3)
IR (Female)	Inhalation rate	m^3/day	Normal	13.68±1.76 (female)	U.S. EPA (2011)
IR (Male)	Inhalation rate	m^3/day	Normal	17.48±2.81 (male)	U.S. EPA (2011)
WHr (Formal NTs)	Working hours per day	Hour	Normal	8.67±0.95 (formal NTs)	Sampling data (Table 2)
WHr (Informal NTs)	Working hours per day	Hour	Normal	9.22±1.03 (informal NTs)	Sampling data (Table 2)
EF	Exposure frequency	days/year	Triangle	83 (48 – 100)	Questionnaire data
ED	Exposure duration	years	Triangle	30 (25 – 35)	U.S. EPA (2011)
AT (Female)	Average lifetime (life expectancy)	years	Normal	68.4±6.82 (Female)	Statistics South Africa (2021)
AT (Male)	Average lifetime (life expectancy)	years	Normal	62.4±6.24 (Male)	Statistics South Africa (2021)
BW (Female)	Body weight	Kg	Normal	67.7±18.58 (Female)	Puoane et al. (2002)
BW (Male)	Body weight	Kg	Normal	66.3±17.62 (Male)	Puoane et al. (2002)
RfC	Inhalation reference concentration	mg/m^3		5 for Toluene	U.S. EPA (2005)
				0.1 for Xylene	U.S. EPA (2003c)
				0.7 for MMA	U.S. EPA (1998)
				0.2 for 2-Propanol	Burleigh-Flayer et al. (1997)
				0.3 for Benzene	U.S. EPA (2003b)
CSF	Cancer slope factor	mg/kg/day		0.029 for Benzene	U.S. EPA (2003b)
				0.045 for Formaldehyde	U.S. EPA (2010)
CDI	Cumulative daily intake	mg/kg.day		output	
CR	Cancer risk	unit less		output	
HQ	Hazard quotient (non-cancer risk)	unit less		output	

MMA, methyl methacrylate; NTs, nail technicians
Values are presented as mean±SD, and median (range)

2.7. Data analysis

Data pre-processing, including data cleaning and visualization, was conducted using Microsoft Excel 2016. Descriptive statistics, including (geometric) means and (geometric) standard deviations, and interquartile ranges, were calculated using ExpoStats, a Bayesian Toolkit (Lavoue, 2015a). Imputation for data below limit of quantification (LoQ) was done using Expostats -NDexpo /RoS tool. NDexpo implements a rigorous censored data treatment method by labeled regression on order statistics (Lavoue, 2015b). For the data in this study, the analytical LoQ was converted into an LoQ sampling concentration of 0.01 mg/m^3.

Self-reported health symptoms were reported as binary answers (yes/no), and results are reported as percentages of technicians responding "yes" to each question. The Welch t-test was used to calculate differences in self-reported symptoms between the formal and informal nail technicians. The self-reported symptoms were categorized into four categories: neurological effects (category A), respiratory effects (category B), eye irritation (category B), and skin irritation (category D) (Supplementary Table S1). The symptoms score was calculated using equation 4. This was applied to all symptom categories with the exception of skin symptoms, which are not related to inhalation exposure:

$$\sum_{Ni}^{ni} symptomscore = \frac{nA}{NA} + \frac{nB}{NB} + \frac{nC}{NC} + \frac{nD}{NB} \tag{4}$$

where *ni* is the number of symptoms reported in that category, and *Ni* is the total number of symptoms in that category.

Self-reported symptoms data (symptoms categories and symptoms score) from the questionnaires were compared with exposure factors, including VOC concentrations and demographic data, using the Pearson correlation coefficient. Concentrations of VOCs assigned to categories with similar health effects were summed (Supplementary Table S2).

To determine the respiratory additive adverse effect, a similar approach to that used by Alaves et al. (2013), who used the American Conference of Governmental Industrial Hygienists (ACGIH) additive mixture formula, was followed. The combined exposure to the chemicals of interest was calculated using the additive agents formula (equation 5) (ACGIH, 2021, DEL, 2021). Based on the reported respiratory effects, the chemicals of interest: for formal nail technicians were ethanol, acetone, ethyl acetate, propyl acetate, toluene, n-butyl acetate, xylene, and 2-propanol. For informal nail technicians, these were ethanol, acetone, ethyl acetate, benzene, MMA, toluene, xylene, and formaldehyde.

$$\sum_{i=1}^{n} \frac{C_i}{T_i} = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \cdots . + \frac{C_n}{T_n} \leq 1 \tag{5}$$

where *Ci* is the measured concentration of a particular chemical of the mixture and *Ti* is the corresponding threshold limit for that chemical. In the additive mixing formula, '*1*' represents the exposure threshold limit for the mixture. If the equation generates a result that is > 1, then the exposure limit for the mixture has been exceeded. The occupational exposure limit (OEL) value used was the South African 8-hour TWA OEL.

3. Results

3.1. Nail technicians' demographic details

Table 2 presents the demographic characteristics of the nail technicians. All formal nail technicians were female, while 43.3% of the informal nail technicians were male. The formal sector nail technicians were older, on average, (33.11±6.41) and had worked longer in the nail industry (5.07±3.71) than the informal nail technicians. Although the informal nail technicians worked longer hours per day, on average, (9.22±1.03) than the formal nail technicians (8.67±0.95), they serviced fewer clients (4.80±1.44) than the formal nail technicians (6.72±1.82).

Table 2 Demographic characteristics of formal and informal nail technicians.

	Formal Nail Technicians (n=54)					Informal Nail Technicians (n = 60)				
Characteristic	n	%	AM	SD	Range	n	%	AM	SD	Range
Age (years)			33.11	6.41	23 – 57			30.12	4.75	22 – 44
Sex										
Male	0	0				26	43.3			
Female	54	100				34	56.7			
Work experience (years)			5.07	3.71	1 – 18			3.28	1.96	1 – 7
No. clients serviced per day			6.72	1.82	3 – 10			4.80	1.44	2 – 9
No. working hours per day			8.67	0.95	8 – 12			9.22	1.03	8 – 12

n, sample number; %, percentage; AM, arithmetic mean; SD, standard deviation.

3.2. *Characterization of volatile organic compounds*

From the 21 VOCs reported, 13 showed a detection frequency of ≥ 30% of the LOD. Formaldehyde concentrations were below the LoD for the formal nail salons, therefore only measurements for formaldehyde from the informal nail salons were analysed. Table 3 summarizes the VOC concentrations that were included in the analysis. Except for formaldehyde, all the VOC concentrations were well below their respective SA 8-hour TWA OEL, as well as the OSHA compliance standards for permissible exposure limits (PELs) or the ACGIH recommended threshold limit values (TLVs). The additive exposure threshold was exceeded in all the informal nail salons.

Table 3 Summary of VOC concentrations (mg/m^3) in the formal and informal nail technicians.

	Formal Nail Salons (n=29)						Informal Nail Salons (n = 29)							
VOC	**n (%)**	**AM**	**SD**	**GM**	**GSD**	**IQR**	**n (%)**	**AM**	**SD**	**GM**	**GSD**	**IQR**	**SA OEL**	**ACGIH TLV**
Ethanol	29 (100)	4.24	1.75	3.87	1.58	3.16 – 5.01	28 (96.6)	6.61	12.30	2.35	4.4	1.19 – 5.50	1900	1880
Acetone	29 (100)	170.2	238.03	108	2.49	64.69 – 162.22	29 (100)	50.53	46.26	24.3	5.11	11.3 – 78.7	1200	594
Ethyl acetate	29 (100)	2.35	1.50	2.01	1.72	1.46 – 3.13	24 (82.8)	0.81	1.88	0.21	5.4	0.08 – 0.58	2900	1440
Benzene	5 (17.2)	0.02	0.003	0.02	1.12	0.019 – 0.023	11 (37.9)	0.02	0.01	0.02	1.46	0.01 – 0.02	3	1.6
MMA	1 (3.4)	0.02	0.02	0.02	1.48	0.017 – 0.017	26 (89.7)	41.66	73.78	8.06	9.48	2.41 – 54.45	410	205
EMA	26 (86.7)	7.21	13.84	1.56	6.93	0.39 – 5.67	24 (82.8)	30.89	51.37	3.57	14.8	0.35 – 32.81	[b]	[b]
Propyl acetate	18 (62.1)	0.06	0.07	0.04	2.23	0.026 – 0.068	3 (10.3)	0.01	0.02	0.02	2.23	0.01 – 0.08	840	417
Toluene	28 (96.6)	0.05	0.04	0.04	1.73	0.03 – 0.06	26 (89.7)	0.04	0.02	0.03	1.47	0.02 – 0.04	151	75
n-Butyl acetate	29 (100)	0.78	0.55	0.62	1.97	0.41 – 0.96	1 (3.4)	0.02	0.019	0.02	1.45	0.02 – 0.12	475	238
Xylene	15 (51.7)	0.04	0.03	0.03	1.88	0.022 – 0.043	23 (79.3)	0.03	0.02	0.03	1.49	0.02 – 0.03	868	87
d-Limonene	28 (96.6)	0.24	0.30	0.14	2.68	0.09 – 0.21	13 (44.8)	0.10	0.2	0.02	6.99	0.01 – 0.08	[b]	[b]
2-Propanol	28 (96.6)	49.9	25.9	43.7	1.72	33.79 – 57.95	7 (24.1)	1.38	2.43	0.34	6.16	0.099 – 1.02	983	492
White Spirits	24 (82.7)	1.09	1.45	0.44	4.81	0.10 – 1.19	27 (93.1)	1.26	0.99	0.9	2.45	0.49 – 1.67	[b]	[b]
Formaldehyde	n.a	n.a	n.a	n.a	n.a	n.a	29 (100)	0.21	0.05	0.21	1.24	0.181 – 0.213	0.2	0.12
[a]Σ Ci/Ti		0.196	0.133	0.17	1.73	0.103 – 0.216		1.21	0.29	1.18	1.25	1.03 – 1.33	1	1

n, sample number; %, detection frequency; AM, arithmetic mean; SD, standard deviation; GM, geometric mean; GSD, geometric standard deviation; IQR, interquartile range; SA OEL, South African occupational exposure limit; MMA, methyl methacrylate; EMA, ethyl methacrylate; n.a, not analysed.

[a]Σ Ci/Ti, ACGIH additive effect (respiratory effect).

[b] Level was not established for ethyl methacrylate, d-limonene and white spirit.

3.3. Self-reported symptoms and exposure factors

Table 4 summarizes the acute health-related symptoms reported by nail technicians experienced over the past four weeks. Sixty percent (n=36) of the informal nail technicians reported having experienced health-related symptoms, compared to 52% (n= 28) of the formal nail technicians. Of the formal nail technicians who reported having symptoms, 32% experienced one symptom, while 68% experienced multiple symptoms. For the informal nail technicians, 19% experienced one symptom, and 81% experienced multiple symptoms across the different categories (Figures 1 and 2). Informal male nail technicians reported more symptoms (69%) than their female counterparts (53%). Some symptoms were perceived to be caused by specific nail products, or to be related to specific nail applications performed. The difference in the number of reported symptoms between the two groups of nail technicians was not statistically significant.

Table 4 Self-reported symptoms among formal and informal nail technicians.

	Formal Nail Technicians (n=54)	Informal Nail Technicians (n = 60)
Category	n (%)	n (%)
Category A (Neurological effects)		
Headache	15 (27.8)	18 (30.0)
Light-headedness	8 (14.8)	6 (10.0)
Category B (Respiratory effects)		
Difficulty breathing	7 (12.9)	5 (8.3)
Chest tightness	12 (22.2)	7 (11.7)
Regular cough	7 (12,9)	8 (13.3)
Wheezing	4 (7.41)	0 (0)
Nasal congestion	11 (20.4)	8 (13.3)
Doctor diagnosed asthma	1 (1.9)	0 (0)
Throat irritation	4 (7.4)	4 (6.7)
Nose irritation	7 (12.9)	13 (21.7)
Category C (Eye irritation)	15 (27.8)	14 (23.3)
Category D (Skin irritation)		
Skin problems	8 (14.8)	9 (15)
Eczema	2 (3.7)	3 (5.0)

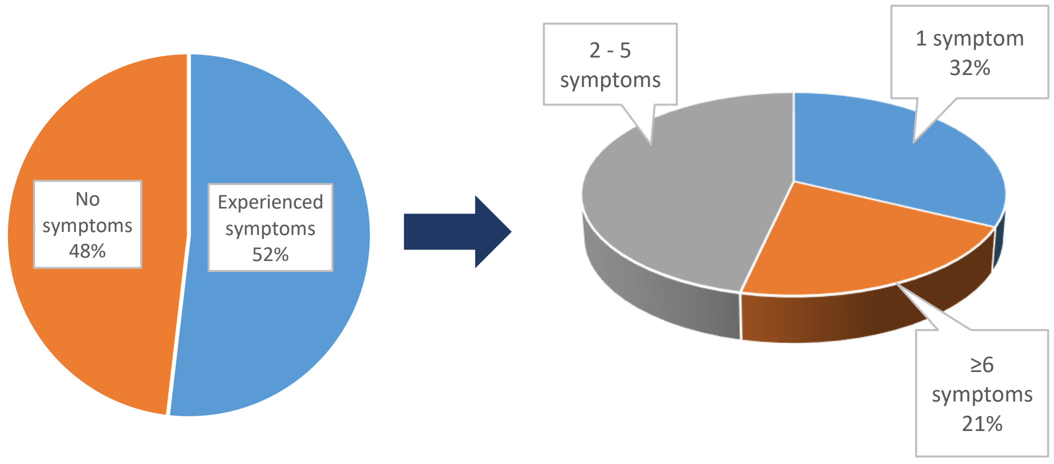


Figure 1 Self-reported ill-health symptoms among formal nail technicians.

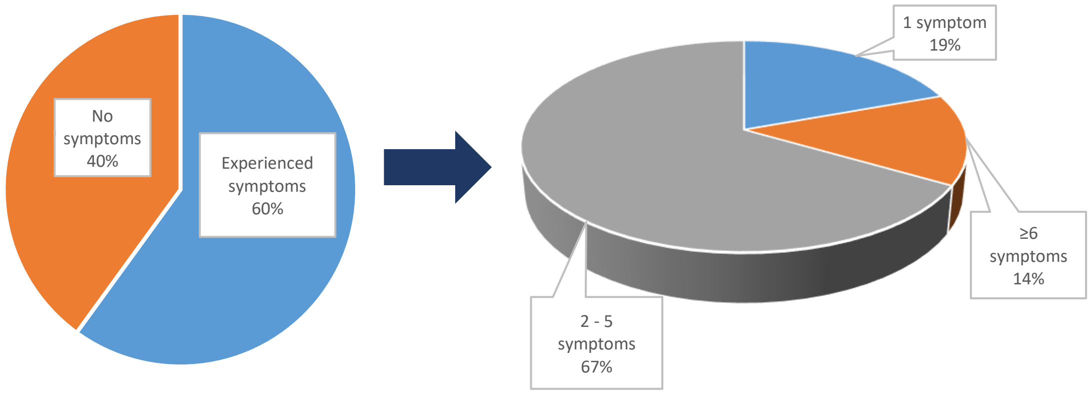


Figure 2 Self-reported ill-health symptoms among informal nail technicians.

Table 5 shows the Pearson correlation coefficients for symptom categories, and corresponding VOC categories and selected exposure variables. A negative significant correlation was found between age and respiratory effects, and sex and neurological effects for informal nail technicians ($p < 0.05$). Respiratory effects and the symptom score showed a positive significant correlation with the working hours among the informal nail technicians ($p < 0.05$).

Table 5 Correlation coefficient and p-values between self-reported symptoms and VOC concentrations among formal and informal nail technicians.

	Formal nail technicians								Informal nail technicians							
	Neurological Effects		Respiratory Effects		Eye irritation		Symptom score		Neurological Effects		Respiratory Effects		Eye irritation		Symptom score	
	r	*p-value*	*r*	*p-value*	*r*	*p-value*	*r*	*p-value*	*r*	*p-value*	*r*	*p-value*	*r*	*p-value*	*r*	*p-value*
Age	0.286	0.424	0.517	0.126	0.607	0.063	0.526	0.118	0.00	1.000	**-0.728***	0.0171	-0.099	0.785	-0.227	0.528
Sex	-	-	-	-	-	-	-	-	**-0.745***	0.013	-0.272	0.447	-0.218	0.545	-0.508	0.134
Work experience	0.118	0.745	0.128	0.726	0.377	0.283	0.259	0.471	-0.388	0.268	-0.359	0.308	-0.393	0.261	-0.477	0.163
Clients serviced	-0.072	0.843	0.342	0.333	0.502	0.139	0.296	0.407	-0.328	0.355	-0.012	0.974	-0.135	0.711	-0.221	0.540
Working hours/day	-0.351	0.321	-0.435	0.209	-0.373	0.289	-0.418	0.229	0.304	0.393	**0.931***	0.000	0.535	0.111	**0.657***	0.039
Cat A VOC	-0.353	0.318	-	-	-	-	-	-	-0.437	0.207	-	-	-	-	-	-
Cat B VOC	-	-	-0.067	0.853	-	-	-	-	-	-	0.131	0.718	-	-	-	-
Cat C VOC	-	-	-	-	-0.162	0.655	-	-	-	-	-	-	-0.343	0.332	-	-
$ACGIH_{index}$	-0.356	0.312	-0.137	0.706	-0.261	0.466	-0.297	0.405	-0.032	0.931	-0.033	0.928	-0.218	0.545	-0.148	0.684

Cat A VOC, VOCs with neurological effects; Cat B VOC, VOCs with respiratory effects; Cat C VOC, VOCs with eye irritation effects; $ACGIH_{index}$, additive respiratory effects.
* Statistically significant ($p < 0.05$)

3.4. *Cancer and non-cancer risk estimation*

Cancer and non-cancer risk were calculated using the cancer slope factor (CSF) and inhalation reference dose (RfC), respectively (Tables 6 and 7). The VOCs investigated in this study are not reported to have carcinogenic effects, except for benzene and formaldehyde (U.S. EPA, 2010, IARC, 2006, U.S. EPA, 2003b, IARC, 2018). Only toluene, xylene, MMA, 2-propanol and benzene were considered for the non-cancer risk characterization. Acetone was not considered because no reference concentration has been established to date, as per the US EPA guidelines (U.S. EPA, 2003a). The median and 95th percentile non-cancer risks for all the nail technicians were higher than 1 for xylene, 2-propanol and benzene, which is indicative of a probability of developing adverse health effects. The same was found for MMA among the informal nail technicians.

Table 6 Health risk assessment (Hazard Quotient) for formal and informal nail technicians by Monte Carlo simulation.

		HQ	
Group	Pollutant	50th Percentile	95th Percentile
Formal female nail technicians	Toluene	3.21×10^{-1}	8.53×10^{-1}
	Xylene	1.33×10^{1}	3.18×10^{1}
	MMA	4.53×10^{-3}	2.77×10^{-2}
	2-Propanol	7.52×10^{3}	1.75×10^{4}
	Benzene	2.22	3.25
Informal female nail technicians	Toluene	2.59×10^{-1}	5.32×10^{-1}
	Xylene	9.48	2.26×10^{1}
	MMA	1.96×10^{3}	7.85×10^{3}
	2-Propanol	2.37×10^{2}	9.66×10^{2}
	Benzene	2.18	4.20
Informal male nail technicians	Toluene	2.89×10^{-1}	5.66×10^{-1}
	Xylene	1.12×10^{1}	2.45×10^{1}
	MMA	2.09×10^{3}	8.73×10^{3}
	2-Propanol	2.32×10^{2}	1.05×10^{3}
	Benzene	2.39	4.66

HQ, Hazard quotients; MMA, Methyl methacrylate

Table 7 shows the estimated increase in lifetime cancer risk for nail technicians in all nail salons, based on 30 years of exposure. Formaldehyde was not assessed for the female nail technicians due to the concentration levels being below the LoD. The estimated cancer risk values (medians and 95th percentiles) for benzene and formaldehyde exceeded the US EPA risk level of 1×10^{-6}. The median lifetime cancer risk for formal female nail technicians for benzene was 1.32×10^{-3}. For informal male nail technicians, the median lifetime cancer risks for benzene and formaldehyde were 1.96×10^{-3} and 2.03×10^{-1}, respectively.

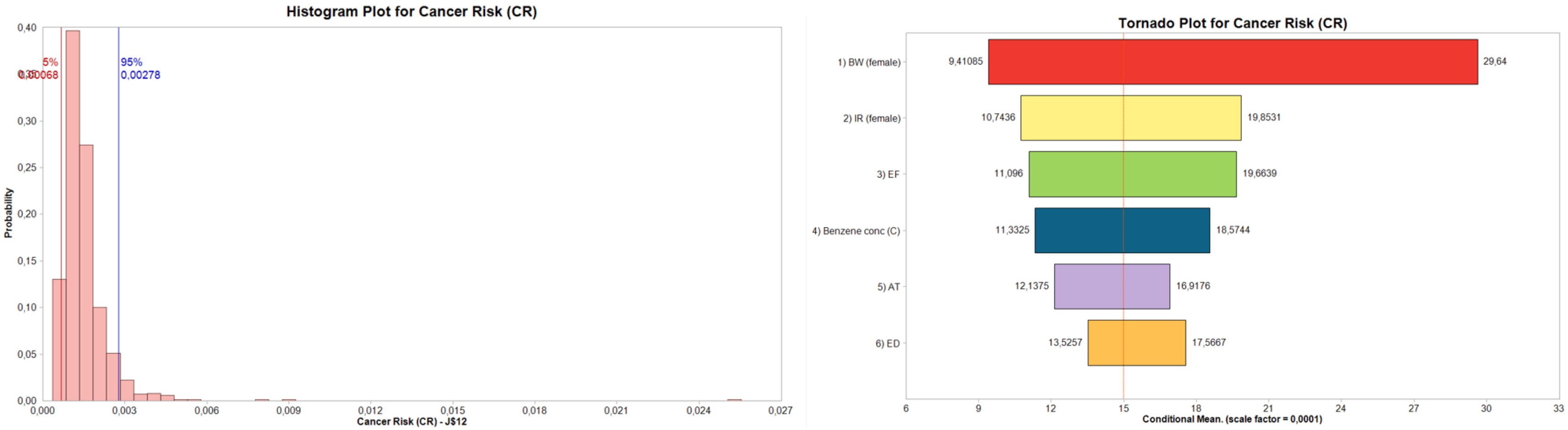
Table 7 Lifetime cancer risk assessment for formal and informal nail technicians, using the Monte Carlo simulation.

Group studied	Pollutant	50th Percentile	95th Percentile
Formal female nail technicians	Benzene	1.32×10^{-3}	2.77×10^{-3}
	Formaldehyde	-	-
Informal female nail technicians	Benzene	1.36×10^{-3}	3.68×10^{-3}
	Formaldehyde	2.48×10^{-2}	5.58×10^{-2}
Informal male nail technicians	Benzene	1.96×10^{-3}	5.47×10^{-3}
	Formaldehyde	2.03×10^{-1}	4.52×10^{-1}

The sensitivity analysis of the non-cancer and cancer risk assessment is represented by tornado plots in Supplementary Figures S1 – S5. The figures show that all the variables, other than the respective VOC concentrations, play a minor role in the non-cancer risk estimation.

The sensitivity analysis in Figure 3 demonstrated that the variations in body weight, inhalation rate and exposure frequency mainly influenced the variation of the estimated cancer risk for formal female nail technicians, while benzene concentration, body weight and inhalation rate influenced the cancer risk for informal female nail technicians. The variables that contributed the most to the estimated cancer risk variation for formaldehyde among the informal male nail technicians were body weight, formaldehyde concentration and inhalation rate (Figure 4).

a)



b)

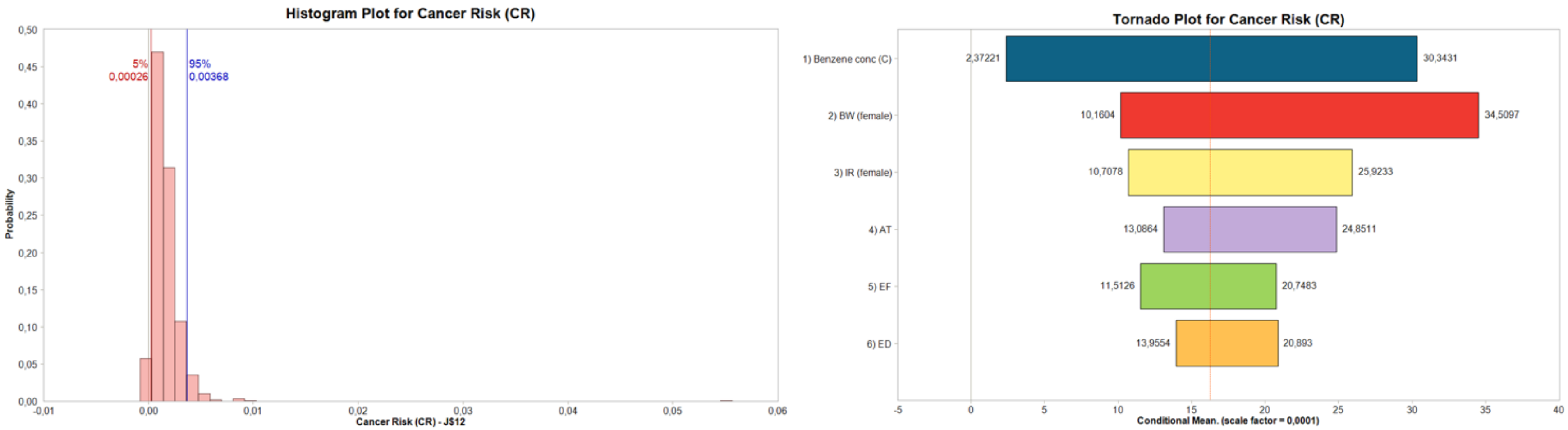


Figure 3 Probabilistic distribution and sensitivity analysis of estimated cancer risk assessment (CR) for (a) benzene among formal female nail technicians, and (b) benzene among informal female nail technicians.

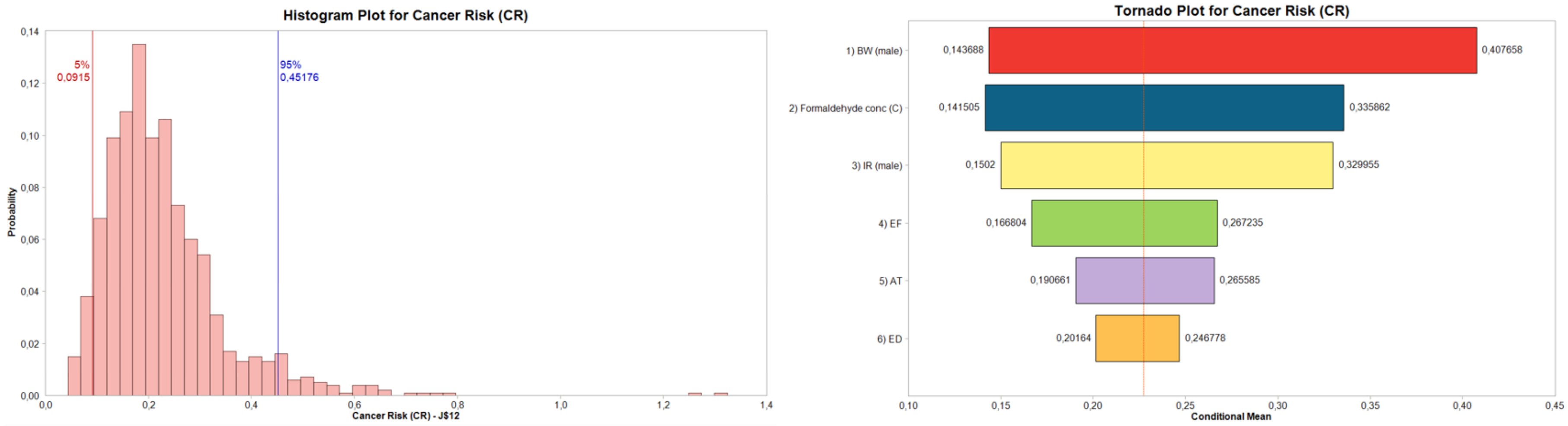


Figure 4 Probabilistic distribution and sensitivity analysis of estimated cancer risk assessment (CR) for formaldehyde among informal male nail technicians.

4. Discussion

In this study, we assessed the exposure of formal and informal nail technicians to selected VOCs and associated health symptoms. We also estimated the non-carcinogenic and carcinogenic risks associated with these exposures.

Working hours varied between the two groups with informal nail technicians working longer hours than the formal nail technicians. However, the formal nail technicians serviced more clients and therefore performed more nail applications. To accommodate this, as described by Keretetse et al. (2023), the formal nail technicians used a quick and easy method to remove existing nail applications by immersing clients' hands in an acetone hot bath. The informal nail technicians commonly used the cotton wool soaked in acetone – a slower method that used less acetone. As reported in the earlier study by Keretetse et al. (2023), acetone concentrations were significantly higher in the formal than the informal nail salons.

More of the formal than the informal nail technicians reported experiencing ill health symptoms (60% and 52%, respectively). The most frequently reported symptoms were headaches, eye irritation, chest tightness, nasal congestion, and skin problems. Other studies have reported similar findings, viz. headaches, confusion, skin irritation, eye irritation, and nose irritation (Quach et al., 2011, Shendell et al., 2018, Lamplugh et al., 2019, Ma et al., 2019, Lteif et al., 2020, Tran et al., 2020), as well as other symptoms such as musculoskeletal disorders (e.g. neck, back and wrist pain). Although our study participants reported similar musculoskeletal related symptoms, these are not presented here.

All three symptom categories namely, respiratory, neurological, and eye irritation showed a negative correlation with their respective VOC categories for formal and informal nail technicians. This could be due to a systematic bias, whereby the symptoms reported may not have been related to the measured exposure concentrations during the assessment days. Acute symptoms may be related to peak exposures rather than daily averaged full shift exposure concentrations (Preller et al., 2004, Virji et al., 2019). Moreover, as shown in Table S2, there was an overlap of VOCs assigned to the different symptom categories, which reduced the resolution between the categories. For formal nail technicians, no variables were significantly correlated with symptoms. For the informal nail technicians, however, there was a negative significant correlation between age and respiratory effects, as well as sex and neurological effects. A positive significant correlation was shown between respiratory effects and the number of hours worked per day. A similar correlation was found for symptom scores.

Task based measurements conducted by the same team (Keretetse et al. (2023)) showed high peak exposures during nail applications that included soak-off to remove existing nail polish. Acrylic applications emitted higher levels of TVOC concentrations than other nail applications. To save time, some of the nail applications were conducted simultaneously on client's hands and feet, but these resulted in an increase in exposure levels.

The MMA concentrations in the informal nail salons are also related to acrylic nail applications where they are more popular than in the formal sector. All VOCs were compared to compliance standards, and all were below their respective exposure limits, with the exception of formaldehyde, which exceeded both the South African 8-hour TWA and the ACGIH TLV. The ACGIH mixed additive effects index for respiratory effects was exceeded in informal nail salons, probably due to the formaldehyde concentration exceeding its exposure limit. These findings are comparable with those described by Alaves et al. (2013). Formaldehyde, a known carcinogen (IARC) and one of the toxic trio, can still be found as an ingredient in some nail polishes and nail hardeners globally. It may also be emitted from building materials, and other products such as those used for hairdressing activities (Hadei et al., 2018, Pexe et al., 2019, Zhong et al., 2019). Many of the informal nail salons in this study included hairdressing activities. The higher formaldehyde levels may have come from hairdressing activities in the informal nail salons.

The VOC concentrations (Table 3) showed, in general, less variability in the formal than the informal sector. This is partly due to the number of clients treated per work hour, i.e. 0.77 versus 0.52 in the formal and informal sector, respectively, but also due to the contribution of VOC emissions from activities of co-workers, as mentioned. This type of bystander exposure dampens the fluctuations of concentrations and was not observed in the informal sector, since only one technician was providing services at a time (Keretetse et al., 2023). In the formal nail salons, nail services performed by co-workers, and associated VOC emissions have contributed to the relatively high TVOC concentrations.

Non-carcinogenic and carcinogenic risk assessment was estimated for selected VOCs, using the hazard quotient and cancer risk for inhalation exposure. The mean concentration for VOCs was used in the calculation, following the consensus to use the arithmetic mean rather than the geometric mean for calculating contaminant concentration levels for risk assessment purposes. When considering an individual's long-term average exposure, it is better presented as the arithmetic mean. Use of the geometric means would have reduced the impact of any high values of the measured concentrations (Lamb et al., 2015).

Since the RfC is for 24 h exposures, a direct comparison of the RfCs with the mean VOC concentrations over the working hours (Table 3) is not appropriate. Instead, an indirect comparison of the VOC concentrations with the RfC was adopted, i.e. by averaging the mean concentration for the working hours over a 24 h day. In our study, we also used the CDI calculations, which is a more explicit way of addressing specific population and sex characteristics, such as body weight and inhalation rate, in the probabilistic risk assessment. The Hazard Quotient compares the averaged 24 h intake with the intake resulting from 24 h exposure at the RfC concentration level.

The 95th percentile, which is considered a worst-case scenario, exceeded the non-cancer risk (HQ) of 1 (unacceptable risk) for xylene, MMA, 2-propanol, and benzene for formal and informal nail technicians. The sensitivity analysis showed that the variation in the concentration of the VOCs, exposure frequency, body weight and average lifetime were the main contributors to the non-cancer risk output variation. For the formal female nail technicians, 2-propanol posed the highest risk of all the VOCs. Although the average concentrations for 2-propanol over the workday were lower than the OEL, the mean concentration averaged over 24-hours exceeded the RfC. For the informal male nail technicians, the same holds for MMA concentrations, with the highest median and 95th percentile HQ estimated values of 2.09×10^3 and 8.73×10^3, respectively. Similar findings were reported by Tran et al. (2020), where the mean MMA non-cancer risk was above 1, and the concentration was 8 times higher than the RfC. These findings may be related to the type of nail products used and the frequency of nail applications, with the acrylic application method used more frequently in the informal sector. All estimated cancer risk values (i.e. median and 95th percentile) for benzene and formaldehyde exceeded the US EPA risk level of 1×10^{-6}, which was similar to findings reported in other nail salon studies (Hadei et al., 2018, Lamplugh et al., 2019, Tran et al., 2020). The sensitivity analysis demonstrated that body weight was the main factor that influenced the variation of estimated cancer risk for formal female nail technicians, while the variation of benzene concentrations was the main factor that influenced the cancer risk output among informal female nail technicians. The variable that contributed most to the estimated cancer risk for formaldehyde among the informal male nail technicians was body weight.

There were several limitations in this study. The relatively small sample size and the sampling method (convenience sampling) of the participants make it challenging to extrapolate the findings to all nail technicians in Johannesburg or South Africa. We only considered inhalation as the route of entry and not dermal exposure. We relied on self-reported symptoms to determine the acute health effects of exposure to VOCs in nail salons. The time difference between administering the questionnaires and taking measurements may have affected the association between the reported symptoms and VOC exposures, since the participants were not asked to report symptoms at the end of each measurement day. Product information was not collected at all participating nail salons, and we relied on published literature for the information and VOC content of commonly used nail products.

Despite these limitations, we generated personal breathing zone concentration data for nail salon workers, including those in the informal sector, which are always difficult to include in studies like these. We also found differences between the two sectors related to salon characteristics, working conditions, type of nail applications conducted, and self-reported symptoms. Although the VOC concentrations were below their respective OELs, the non-cancer risk estimates exceeded the HQ of 1, which indicated that continued exposure may lead to long-term adverse health effects. The lifetime cancer risk was higher than the recommended US EPA risk level (1×10^{-6}) for benzene and formaldehyde. This represents a cancer risk of leukaemia from benzene exposure, and nasopharyngeal and oropharyngeal cancer resulting from exposure to formaldehyde. Similar findings were reported in a study conducted in nail salons in Colorado, USA.

5. Conclusion

This study contributes to the research on nail technicians' exposure to a variety of VOCs emitted from nail products used on a daily basis. There were differences in age, sex, and working conditions between the formal and informal nail technicians. The informal nail technicians reported more ill health symptoms than the formal nail technicians. The most common symptoms were headaches, eye irritation, respiratory effects, and skin disorders. Informal male nail technicians reported the highest number of symptoms than their female counterparts.

Although exposure levels for the informal nail technicians were below the recommended OELs for the selected VOCs, with the exception of formaldehyde, the findings suggest that there is a risk of developing both carcinogenic and non-carcinogenic health effects. Among both the formal and informal nail technicians, the estimated non-cancer risks for xylene, MMA, 2-propanol, and benzene were higher than the acceptable limit of 1, indicating a risk of developing adverse health effects. All the estimated cancer risks study for benzene and formaldehyde exceeded the EPA risk level. The sensitivity analysis for benzene and formaldehyde showed that VOC concentration, exposure frequency, body weight, inhalation rate, and average lifetime (life expectancy) contributed the most to the cancer risk. Efforts to reduce exposure and regulate working hours, thereby reducing the frequency of exposure, should be made to protect nail technicians from developing adverse effects from long term exposure to VOCs. The association between exposure to VOCs and skin related disorders also needs to be explored.

of 1 x 10^{-6}

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7. Author Contribution

GK, DB, and GN: conceptualization and design of the study. GK: literature review, original draft of manuscript and data collection. GK, DB: data analysis and interpretation. DB and GN: critical review and editing of the manuscripts. All authors contributed to the article and approved the submitted version.

8. Conflict of Interest

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

9. Acknowledgements

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10. Data Availability

The raw data supporting the conclusions of this article are available from the corresponding author on reasonable request.

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Appendix 3

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Exposure of formal and informal nail technicians to organic solvents found in nail products

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Nail technicians are exposed to volatile organic compounds (VOCs) emitted from nail products used in their daily work, which may cause adverse health effects. This study aimed to assess VOC exposure of nail technicians in the South African formal and informal sectors and to provide a task-based exposure assessment of different nail applications. Personal passive sampling was conducted on 10 formal and 10 informal nail technicians located in the northern suburbs of Johannesburg and the Braamfontein area, over 3days. Real-time measurements were taken to determine task-based peak exposures. The number of clients serviced, working hours, type of nail application, type of ventilation, room volume, and carbon dioxide (CO_2) concentrations, were also recorded. There were differences in the nail products used, the types of nail applications performed, the number of clients serviced, and breathing zones VOC concentrations of the formal and informal nail technicians. Some formal nail salons were equipped with mechanical ventilation while the informal nail salons relied on natural ventilation. CO_2 concentrations were higher in the informal than the formal nail salons and increased during the course of the working day. Formal nail technicians were exposed to higher total volatile organic compounds (TVOC) concentrations than informal nail technicians, which may be due to the different nail application procedures as well as 'background' emissions from their co-workers—the bystander effect. Acetone was the predominantly detected VOC: the formal nail technicians were exposed to significantly higher TWA (8h) concentrations [geometric mean (GM) 43.8ppm, geometric standard deviation (GSD) 2.49] than were the informal nail technicians (GM 9.87ppm, GSD 5.13). Methyl methacrylate among the informal nail technicians was measured at 89.7% detection frequency, far higher than that among the formal nail technicians (3.4%). This may be attributed to the observed popularity of acrylic nail applications in this sector. Nail applications involving soak-off gave rise to high TVOC peaks at the start of the nail application process. This is the first study to compare organic solvent exposures among formal and informal nail technicians and determine task-based peak exposures. It also brings attention to the often-overlooked informal sector of this industry.

KEYWORDS

volatile organic compounds, passive sampling, task-based monitoring, VOC profile, bystander exposure, adjusted TVOC

1. Introduction

Nail care service, as part of the beauty industry, comprises both the formal and informal sectors in South Africa. The formal sector comprises formalized and registered businesses, some of which are franchises with formal employment structures, regulated working hours, and monthly salaries. The informal sector comprises nail salons that are not registered or regulated by the state, are mostly self-owned or part of an existing business such as a hair salon, and are categorized by irregular working hours and unstable wages (1, 2). No longer a new industry, the nail care industry has grown exponentially, both locally and internationally, with the US projecting growth in the number of licensed manicurists and pedicurists by more than 10% from 2018 to 2028 (3–5).

Nail technicians spend their working days providing nail care services, which include manicures, pedicures, nail polish applications, ultra-violet (UV) gel applications, acrylic nail applications, and nail extensions in the form of artificial nails. These applications make use of a wide variety of products, comprising a cocktail of chemical substances. Products include nail polishes, nail polish removers, nail hardeners, artificial nails, nail tip adhesives, artificial nail removers, and disinfectants (6). Chemical substances in the nail products are typically aromatics hydrocarbons (toluene, ethyl benzene, xylene), aldehydes (formaldehyde), esters (ethyl acetate, butyl acetate, vinyl acetate, methyl methacrylate (MMA), ethyl methacrylate (EMA)), ketones (acetone and methyl ethyl ketone), alcohols (ethanol, isopropyl alcohol, and n-butyl alcohol), plasticisers (dibutyl phthalate, triphenyl phosphate), and terpentines (pinene, limonene, camphor, menthol) (7–9). Many of these chemicals are associated with health effects from exposure via inhalation and skin contact, including cancers, allergies, and respiratory, neurologic and reproductive disorders (4, 7, 10–13). Both nail technicians and their clients are exposed to these chemicals.

In 1974, the United States Food and Drug Administration (US-FDA) banned the use of MMA in cosmetic products due to its sensitizing effects, and reported incidents of fingernail damage and deformity, as well as contact dermatitis. It was subsequently replaced with EMA (14). Despite 32 states in the US also banning MMA (15), several exposure assessment studies in nail salons have reported its presence (12, 16–19). Some nail polishes contain harmful substances such as toluene, dibutyl phthalate (DBP) and formaldehyde, commonly known as the 'toxic trio' (20). There was a move in the US during the early 2000s to reduce the use of such harmful substances in nail products, with some nail polishes declared to be DBP-free or free from the 'toxic trio' (3, 21). These actions created awareness and helped regulate the chemical composition and labeling of nail products. The challenge is in enforcing compliance since cosmetic products and ingredients do not need US-FDA premarket approval, with the exception of color additives (22). The onus is on the manufacturers to ensure that these harmful substances are excluded from their products and to provide labels listing the contents on their products, as well as safety data sheets to consumers and nail salons. In South Africa, the formal sector can standardize the purchase of products, using procurement structures and procedures, which reduces the risk of sourcing products that contain banned substances or are not adequately labeled. The informal sector salons and technicians, however, procure products that are readily available and affordable, and which might contain banned and unsafe chemicals. This practice was reported in a study in Uganda where nail salons used cheap cosmetics to keep costs low (23).

Various exposure assessment methods have been used to measure VOC exposures in nail salons, including passive samplers, active samplers, direct reading instruments, and combinations thereof. For example, some researchers have conducted personal exposure measurements within the worker's breathing zone, covering the full shift or up to 80% of the shift (4, 7, 18); some have measured ambient concentrations at strategic locations within the nail salon to assess within salon variability (3, 11); and others have used area measurements with the sampler positioned as close as possible to the worker's breathing zone (12, 17, 19, 24).

No studies assessing nail technicians' exposures to VOCs in nail products have been conducted in South Africa until now. The objectives of this study were to assess exposures of nail technicians, in the formal and informal sectors of the nail industry, to VOCs emitted from nail products, and to provide a task-based exposure assessment of different nail applications provided in the salons.

2. Materials and methods

2.1. Study population

This study was conducted in nail salons in the City of Johannesburg. Ten nail salons represented the informal sector in the Braamfontein area and six nail salons represented the formal sector in the northern suburbs. The formal nail salons were franchises of one of the largest local beauty companies, while the informal nail salons comprised unregistered nail salons, some of which operated inside hairdressing salons. Ten nail technicians from 10 informal nail salons, and 10 from six formal salons agreed to participate in the study.

2.2. Personal exposure measurements

The data collection procedure started with a brief walkthrough of each nail salon to identify the types of ventilation, the layout of the salon, the location of the nail service station(s), and other services offered such as massages, waxing, and hairdressing. Personal exposure measurements were collected by means of diffusion/passive sampling (Radiello® Passive sampler, Sigma Aldrich). Before sampling, the sorbent cartridge was removed from its glass storage tube and inserted into the diffusive body, taking care not to touch the cartridge. The passive sampler was attached to the lapel of the participant in order to obtain a sample within the breathing zone. Sampling devices were deployed to measure at least 80% of the work shift, over a period of three consecutive days, for each nail technician. A total of 60 personal exposure measurements in the formal ($n = 30$) and informal ($n = 30$) nail salons were collected. Field blanks were also collected to check for contamination during transport. A data capture sheet was used to record information such as the time that the passive sampler was opened and donned, the number and types of nail applications performed, the duration of the nail application procedures, personal protective equipment used, and other control measures that were in place. At the end of the sampling period, the passive sampler was detached from the participant's lapel, placed in the glass tube, capped, labeled and stored at <5°C.

2.3. Task-based monitoring

Task-based exposure measurements were carried out using a MiniRAE 3,000 Photoionization detector (PID; RAE Systems, Sunnyvale, CA) to measure peak exposures during specific nail application activities. The task-based exposure measurements are key to determining peak exposures in order to target interventions. The PID was used for continuous detection of TVOCs, using a 10.6 eV lamp (range 0.1–15,000 ppm). Prior to each day of sampling, the PID was calibrated according to the manufacturer's recommendations, which included zeroing the instrument with zero-grade air (fresh air) and span calibration with a single concentration of 100 parts per million (ppm) isobutylene gas. The direct reading instrument was programmed to data log concentrations every minute. Measurements were taken as close as possible to the nail technician's breathing zone during the full duration of the nail application.

Salon dimensions were measured with a laser distance measurer (Laser Measurer Model GLM 80; Bosch). Multiple air quality parameters were measured at each salon at the start and the end of the work day—indoor and outdoor. These included CO_2, used as a proxy for ventilation in the nail salons, temperature, and relative humidity (IAQ-Calc Indoor Air Quality Meter Model 7,545; TSI, Inc.). Measurements were data logged at 1-min intervals. Outdoor measurements were collected within 50 m of the nail salon and 150 m from the road or carpark.

2.4. Chemical analysis

The sorbent from each sample was extracted using 2 ml of carbon disulfide (CS_2). The sample was stirred and allowed to stand for 30 min. Gas chromatography with a flame ionization detector was used to quantify the concentrations of VOCs. Chromatographic separation was performed using a DB-624 column (0.25 mm ID, 30 m length, 1.4 μm film thickness) for quantification and a DB-WAX column (0.25 mm ID, 30 m length, 1.5 μm film thickness) for verification, with a split injection of 3 μl and split flow of 20 ml/min. The carrier gas was nitrogen at a constant pressure of 5 psi. The injector temperature was 220°C, and the detector temperature was 200°C. The following temperature program was used: oven initial temperature of 35°C (hold for 10 min), ramp at 5°C/min up to final isotherm of 175°C (hold for 7 min). The total time for the analysis was 45 min. Peak areas were extracted by MSD ChemStation macro program, adjusted for internal standards, and transferred to an excel spreadsheet.

The average concentration over the exposure time interval was calculated from the mass of the analyte found on the cartridge and exposure time, without introducing any corrective factor. Average concentration, C (μg/m^3) over the entire exposure time was calculated as:

$$C\left[\mu g.m^{-3}\right]=\frac{m\left[\mu g\right]}{Q_k\left[ml.\min^{-1}\right]*t\left[\min\right]}1,000,000 \quad (1)$$

Where, Qk is the sampling rate, m is the mass of analyte in μg, and t is the sampling duration in minutes.

Based on the literature review, and information obtained from the labels of the products used and the ingredients list (although not always listed), the following compounds were quantified: ethanol, acetone, methyl ethyl ketone (MEK), ethyl acetate, benzene, trichloroethylene, methyl methacrylate, ethyl methacrylate, propyl acetate, methyl isobutyl ketone (MIBK), toluene, perchloroethylene, n-butyl acetate, ethyl benzene, xylene, d-limonene, chloroform, 2-propanol, 1-propanol, and white spirits. To simplify the calculation, the limit of detection for all compounds was set at 0.50 μg/ml and, the average lowest concentration value of the samples was set at 0.004 ppm.

2.5. Data analysis

Data pre-processing and visualization were conducted using Microsoft Excel 2016. Data were analyzed using the following statistical tool packages and calculators: ExpoStats, a Bayesian Toolkit (25), BWStat (version 2.1; Belgian Society for Occupational Hygiene), IHMod (version 2.0, AIHA, 2021), and Stata software (version 17; StataCorp LLC, Texas, USA). Normality of VOC concentrations was assessed using the Expostats NDistrib tool for assessing goodness of fit for the lognormal and normal distributions. Thirteen VOCs with a detection frequency of ≥30% were selected from the 20 reported VOCs for further analysis. Descriptive statistics, including geometric means and standard deviations, and interquartile ranges, were calculated using ExpoStats. Given that the type and number of VOCs differed within and between the two sectors, with some of the VOCs having much higher concentration compared to others. Summing the concentrations would result in skewed results. Therefore the adjusted total VOC concentration was calculated to enable comparison. Adjusted TVOC concentration was calculated using the 13 detected VOCs, after correcting by their respective evaporation rate relative to the evaporation rate of d-limonene (the VOC with the lowest evaporation rate; Supplementary Table S1). The evaporation rates were calculated by means of Hummel's equation (26), using the IHMod 2.0 mathematical model supporting files. The ratio of the evaporation rate of each VOC and that of d-limonene was used to correct the concentration of each individual VOC in what is referred to as the weighted concentration. The sum of these individual VOC weighted concentrations was the adjusted TVOC concentration in mg/m^3. The f-test was used to calculate variance and the independent t-test to calculate the difference in adjusted TVOC between the formal and informal nail technicians.

Imputation for data below the limit of detection (LoD) was performed for the VOC concentrations, using Expostats-NDexpo/RoS tool (9, 27). NDexpo is a web application that implements a rigorous censored data treatment method, the regression on order statistic (Robust ROS), as described by Helsel (28). This approach is based on fitting detected values to a lognormal distribution and then predicting a replacement value for each nondetect as a function of the fitted distribution, and its rank among the detected values. The analytical LoD and LoQ of 0.50 and 1.65 (3.3 times LoD) microgram/ml, respectively, were converted into a LoQ sampling concentration of 0.0132 ppm. The independent t-test was used to investigate differences between formal and informal nail technicians, using the natural log (ln) transformed concentrations of the six VOCs with ≥80% of all observation above LoD.

Associations between VOC concentrations and other variables were evaluated using Pearson's correlation coefficient. The variability of acetone concentrations, specifically within- and between-salon variability, and within- and between nail technicians in the respective sectors, were evaluated using a one-way analysis of variance (ANOVA) test, implemented in BWStat version 2.1, after ln-transforming the data. Task-based measurements were graphically represented as time series plots, showing detailed phases of each reported nail application. These were only used as qualitative indications of TVOC exposure peaks during a specific nail application.

The differences in the indoor CO_2 concentrations over the workday (ΔCO_2) were determined by calculating the difference between outdoor and indoor CO_2 concentration at the start and the end of the day. This is a similar approach used by Alaves (17) who calculated the change in CO_2 ("CO_2 differential"), i.e., the difference in pre- and post-sampling CO_2 measurements. The ΔCO_2 was correlated against the number of clients serviced.

The study was approved by the University of the Witwatersrand Human Research Ethics Committee (HREC): certificate number M171184.

3. Results

3.1. Nail salon characteristics

All nail salons in this study offered basic nail services, including manicures and pedicures, nail polish applications, gel applications, and acrylic applications. Most of the nail applications began with an acetone soak-off process to remove existing nail applications. Different methods of nail polish removal, referred to as soak-off, were observed. The formal nail technicians most commonly administered the soak-off by immersing the client's nails in an acetone hot bath. This is done by filling a bowl (large enough for the client's fingers to fit) with acetone and placing it inside a larger bowl filled with hot water. This heats the acetone slightly, which speeds up the nail application removal process. The method is quick and reduces the duration of the nail application process. The informal nail technicians made use of cotton wool pads soaked in acetone, which were applied to the client's nails, and wrapped in tin foil. This method takes longer but uses less acetone than the hot bath method.

The most common applications in the formal and informal nail salons were gel and acrylic nail applications, respectively. Formal nail salons used similar products from known brands, procured through a structured company system, while informal nail salons used a variety of brands and suppliers.

Table 1 shows a comparison of basic characteristics of environments in the formal and informal salons. Formal nail technicians provided nail services to more clients (5.8 ± 1.7) than did informal nail technicians (3.3 ± 2.0). However, the mean number of working hours per day was higher in the informal nail salons (9.7 ± 1.2 hours). Together, this suggests that the mean duration per application was longer in the informal than the formal nail salons. The mean room volume of the formal nail salons (154 m^3) was almost twice that of the informal nail salons (86.1 m^3). All the informal nail salons were located in hair salons opening to the roadside, while five (83.3%) of the formal nail salons were located in a shopping center/strip mall with the main door opening to a carpark; only one formal nail salon was located inside a shopping mall with a central walkway where retail stores face one another. Informal nail salons relied predominantly on natural ventilation through open doors (no windows), while nail salons in the formal sector made use of both

TABLE 1 Characteristics of formal and informal nail salon environments.

Variable	Formal nail salons (*n* =6)					Informal nail salons (*n* =10)				
	n	%	AM	SD	IQR	*n*	%	AM	SD	IQR
Number of clients serviced			5.8	1.7	4–7			3.3	2.0	2–4
Working hours per day (hours)			8.6	0.5	8–9			9.7	1.2	9–10
Salon location										
Roadside	0	0				10	100.0			
Shopping center/strip mall	5	83.3				0	0			
Shopping mall	1	16.7				0	0			
Ventilation										
Natural ventilation	4	66.6				10	100.0			
Mechanical general ventilation (HVAC)	6	100.0				0	0			
HVAC system operational	2	33.3				0	0			
Room volume (m^3)			154	12.8	151–162			86.1	37.8	56.4–95.0
CO_2 (ppm)*			492	119	404–551			713	299	522–887
ΔCO_2 (ppm)			35	176				−52	400	
Temperature (°C)			24	2.4	23–26			26	1.4	26–28
Relative humidity (%)			39	13.6	25–49			53	7.5	48–57

*Average indoor CO_2 levels at the end of the day.
AM, arithmetic mean; SD, standard deviation; IQR, interquartile range; HVAC, heating, ventilation and cooling system.

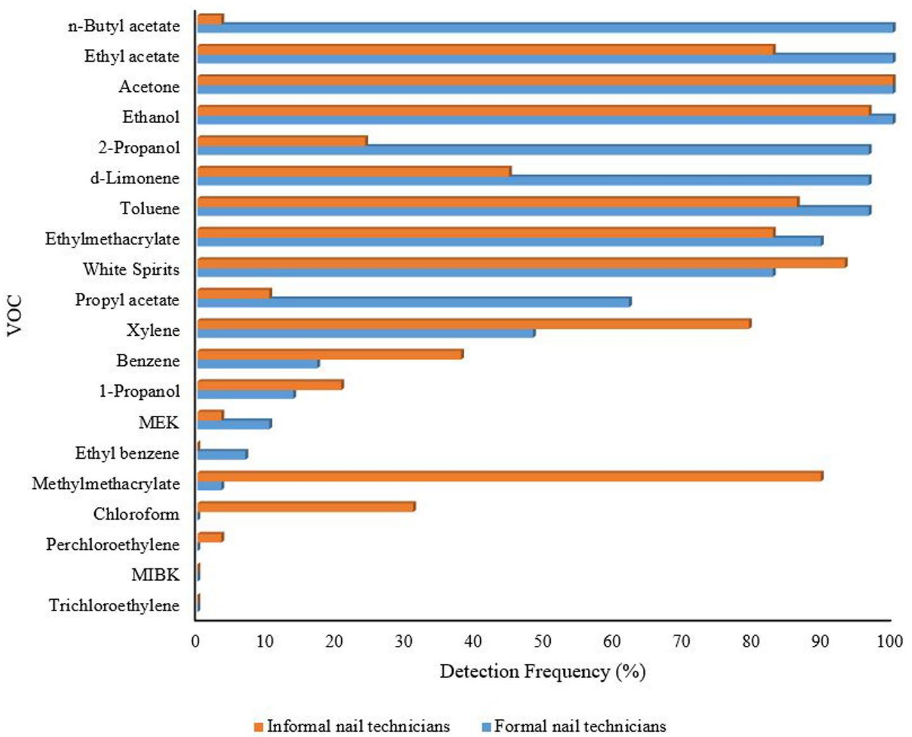

FIGURE 1
Profile of all volatile organic compounds (VOCs) detected in shift-based measurements among formal and informal nail technicians.

natural and mechanical ventilation in the form of heating, ventilation and cooling (HVAC) systems. While all participating formal nail salons had an HVAC system, only two (33.3%) used it during the sampling period. In general, salons that were not using their HVAC systems relied on natural ventilation by opening their doors. None of the participating salons had local extraction ventilation (LEV) systems. Mean temperature and relative humidity in the informal nail salons were higher (AM 26°C, SD 1.4 and AM 53%, SD 7.5, respectively) than those in the formal nail salons (AM 24°C, SD 2.4 and AM 39%, SD 13.6, respectively). Informal nail salons had, on average, higher indoor CO_2 concentrations (AM 713 ppm, SD 299) than the formal nail salons (AM 492 ppm, SD 119) at the end of the working day. The mean ΔCO_2 in the formal nail salons showed an increase in CO_2 during the course of the day (AM 35 ppm, SD 176) while, in the informal nail salons, there was a decline (AM −52 ppm, SD 400).

3.2. Concentration levels of organic solvents

Sixty personal exposure measurements were collected in the formal ($n = 30$) and informal ($n = 30$) nail salons. One informal study participant did not present for work on the third day of the assessment, and all measured VOCs for one formal participant were below the limit of detection for day 3 of the assessment. The latter scenario may have been a result of mishandling the sampling device during the measurement period. Thus, two samples were excluded from the analysis, resulting in a sample size of 58, i.e., 29 in each group. Field blanks showed negligible VOC levels, confirming that transport, storage, and handling activities did not contaminate the sampling device.

The chemical profiles of the full shift personal exposure sampling of the formal and informal nail technicians are shown in Figure 1. Of the 20 VOCs reported, 13 showed a detection frequency of ≥30% the LoD, *viz.* n-butyl acetate, ethyl acetate, acetone, ethanol, 2-propanol, d-limonene, toluene, ethyl methacrylate, methyl methacrylate, white spirits, propyl acetate, xylene, and benzene.

As shown in Table 2, VOC concentrations differed between the formal and informal nail salons. Six of the detected VOCs, namely ethanol, acetone, ethyl acetate, ethyl methacrylate, toluene and white spirits, had detection frequency (DF) of 80% above the LoD in both the formal and informal nail salons. For formal nail technicians, the GM of the concentrations for acetone, ethyl acetate and ethanol that presented with 100% DF was significantly higher than that for the informal nail technicians, where the GSDs were much higher. A significant difference was also seen in white spirit concentration between the two groups ($p < 0.05$). Noticeably, a 100% DF was observed for n-butyl acetate among the formal nail technicians, whereas this substance was detected in only one of the 29 samples (3.4%) among the informal nail technicians. Methyl methacrylate was found in 89.7% of the samples among the informal nail technicians compared to only one sample (3.4%) among the formal nail technicians.

Figure 2 shows box and whisker plots of the distribution of VOC concentrations in the formal and informal nail salons, corrected for their respective evaporation rates (Supplementary Table S1). The formal nail technicians had a higher adjusted mean TVOC (GM

TABLE 2 Summary of volatile organic compounds (VOC) concentrations (ppm) in the formal and informal nail salons.

VOC	Formal nail salons (n=6)					Informal nail salons (n=10)					p-value*
	n	%	GM	GSD	IQR	n	%	GM	GSD	IQR	
Ethanol	29	100.0	2.06	1.58	1.68–2.66	29	96.6	1.24	4.4	0.633–2.92	<0.05
Acetone	29	100.0	43.80	2.49	26.3–66.1	29	100.0	9.87	5.13	4.59–32	<0.05
Ethyl acetate	29	100.0	0.559	1.72	0.406–0.868	29	82.8	0.058	5.44	0.023–0.16	<0.05
Benzene	29	17.2	0.004	1.33	0.004–0.005	29	37.9	0.003	2.33	0.002–0.005	
Methyl methacrylate	29	3.4	0.002	–	–	29	89.7	1.970	9.48	0.588–13.3	
Ethyl methacrylate	29	89.7	0.334	6.93	0.083–1.21	29	82.8	0.765	14.8	0.0748–7.03	>0.05
Propyl acetate	29	62.1	0.007	3.12	0.003–0.016	29	10.3	0.004	2.23	0.002–0.006	
Toluene	29	96.6	0.010	1.81	0.007–0.015	29	86.2	0.008	1.56	0.006–0.010	>0.05
n-Butyl acetate	29	100.0	0.131	1.97	0.085–0.202	29	3.4	0.002	–	–	
Xylene	29	48.3	0.005	2.64	0.003–0.009	29	79.3	0.006	1.69	0.005–0.008	
d-Limonene	29	96.6	0.025	2.75	0.015–0.038	29	44.8	0.004	6.99	0.001–0.003	
2-Propanol	29	96.6	17.80	1.72	13.7–23.6	29	24.1	0.139	6.16	0.041–0.416	
White Spirits	29	82.8	0.076	4.81	0.017–0.204	29	93.1	0.155	2.45	0.084–0.288	<0.05

n, sample number; %, detection frequency; GM, geometric mean; GSD, geometric standard deviation; IQR, interquartile range. *Student *t*-test.

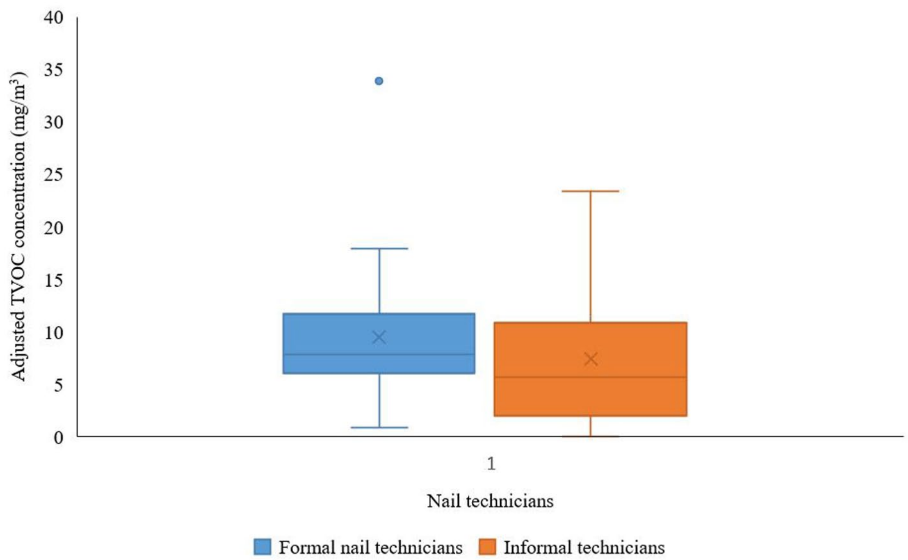

FIGURE 2
Comparison of the adjusted total volatile organic compounds (TVOC) concentrations of 13 measured solvents detected in formal and informal nail technicians. In the box plots, the boundary of the box closest to zero indicates the 25th percentile (1st quartile), the line within the box marks the median, the "*x*" within the box marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile (3rd quartile). Whiskers above and below the box indicate the upper and lower extremes. The circle above the whiskers indicates the outlier or the value greater than 1.5 the value of the third quartile.

7.24 mg/m^3, GSD 1.91) than the informal nail technicians (GM 4.12 mg/m^3, GSD 3.84). There was no statistically significant difference in the adjusted TVOCs between formal and informal nail technicians. Although acetone had the highest concentrations in both groups, it contributed only 39.9 and 13.6% to the adjusted TVOC concentrations in the formal and informal sectors, respectively. With 46.9% contribution to the TVOCs, 2-propanol was the dominant VOC in the formal nail salons, whereas both MMA an EMA contributed the most to the TVOCs in the informal sector, *viz.* 39.3 and 33.3%, respectively.

One-way ANOVA-tests were conducted to compare the variability of acetone—the VOC with the highest concentrations—between and within nail salons in the formal and informal sector (Supplementary Tables S2, S3). The acetone concentration differed significantly, between the informal nail salons [$F(9, 19) = 8.88$, $p < 0.001$], and between the formal nail salons [$F(5, 23) = 4.08$, $p = 0.008$].

Table 3 shows the Pearson's correlation coefficients for selected VOCs and some of the salon characteristics, i.e., number of clients serviced, and ΔCO_2. The VOC contributing the most to the adjusted TVOC in the formal sector—2-propanol—was included in the

TABLE 3 Pearson's correlation coefficients and value of ps between volatile organic compounds (VOCs) concentration, number of clients seen per day and ΔCO_2 among formal and informal nail salons.

VOC	Formal				Informal			
	No. of clients		ΔCO_2		No. of clients		ΔCO_2	
	r	*p*-value	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value
Ethanol	0.023	0.902	−0.124	0.521	0.375*	0.045	0.219	0.543
Acetone	−0.181	0.347	0.131	0.499	0.562*	0.002	−0.171	0.636
EA	−0.021	0.912	−0.364	0.052	0.017	0.931	0.076	0.835
EMA	−0.087	0.652	−0.246	0.198	0.663*	0.000	−0.092	0.801
Toluene	−0.234	0.222	0.019	0.921	−0.065	0.738	0.247	0.491
2-Propanol	0.173	0.370	−0.309	0.103	0.239	0.213	0.104	0.776
White spirits	−0.157	0.418	−0.049	0.802	0.259	0.176	−0.009	0.979

EA, ethyl acetate; EMA, ethyl methacrylate. ΔCO_2, the difference in the indoor CO_2 concentrations over the workday.

correlation analysis. Concentrations of ethanol, acetone, and ethyl methacrylate showed a significant correlation with the number of clients serviced among the informal nail technicians ($p < 0.05$, Table 3).

As shown in Supplementary Table S4, there were strong and significant correlations between ethyl methacrylate and ethanol ($r = 0.77$; $p \leq 0.01$), 2-propanol and ethanol ($r = 0.80$; $p \leq 0.01$), and 2-propanol and ethyl methacrylate ($r = 0.55$; $p \leq 0.01$). Acetone, ethyl methacrylate, white spirits, and the number of clients serviced were negatively correlated with ΔCO_2, which ranged from −0.01 to −0.17, for the formal nail salons (Table 3). In the formal nail salons (Supplementary Table S5), there were strong and significant correlations between ethyl acetate and ethanol ($r = 0.55$; $p = <0.01$), toluene and acetone (0.87; $p = <0.01$), 2-propanol and ethanol ($r = 0.53$; $p \leq 0.01$), and 2-propanol and ethyl acetate ($r = 0.58$; $p \leq 0.01$). Negative correlations were observed in the formal nail salons between the concentrations of ethanol, ethyl acetate, ethyl methacrylate, 2-propanol, white spirits, and ΔCO_2.

3.3. Task-based exposures

Figure 3 shows time profiles of peak exposures to volatile organic solvents (ppm) of various nail applications (a: nail polish application (buff and paint), b: gel application; c: soak off pedicure and gel application; d: soak off and acrylic application) in the formal nail salons. Typical nail applications performed in a formal nail salon are basic manicures and pedicures, UV gel or gelish applications, bio-sculpture applications, normal paint applications (also referred to as buff and paint), and acrylic applications. Sometimes, two nail technicians work simultaneously on one client, conducting multiple nail applications (Figure 3B). Figure 4 shows soak-off and bio sculpture applications on a client's hands, and pedicure, provided simultaneously by two nail technicians.

4. Discussion

The objective of this study was to assess the breathing zone concentration of key organic solvents generated from nail products during nail application services, among formal and informal nail technicians. We also assessed task-specific exposures to identify short duration and peak exposure patterns.

Differences were noted regarding the basic characteristics of the nail salons. All the formal nail salons were fitted with mechanical ventilation in the form of ceiling exhaust fans and HVAC systems, although only two nail salons (33.3%) operated their ventilation systems at the time of sampling. All informal nail technicians, on the other hand, relied on natural ventilation (open doors). The rooms of the formal nail salons were larger, by volume, than those of the informal nail salons. Interesting to note is that the adjusted TVOC concentration was higher in the formal than the informal nail salons where only natural ventilation was used. Goldin et al. (29) reported that TVOC concentrations were inversely associated with ventilation, where salons with poorer ventilation had higher CO_2 concentrations and significantly higher TVOC concentrations. Park et al. (7), however, reported that concentrations measured in salons with general mechanical ventilation systems were higher than those without the systems. They speculated that the ventilation system, especially the ceiling exhaust duct, may have contributed to the spread of chemicals in the room and toward the worker's breathing zone. Persily (30) proposed using CO_2 as an indicator or metric of outdoor ventilation rates (30). This metric takes into consideration that indoor CO_2 depends on several factors, including the occupants' rate of generating CO_2, outdoor air ventilation rates, time of occupancy, and outdoor CO_2 concentrations.

In our study, we calculated the ΔCO_2 and found that the CO_2 concentrations decreased during the day in the formal nail salons but increased in the informal nail salons, suggesting that the formal salons had better ventilation. The informal nail salons had a higher mean CO_2 concentration than the formal nail salons. Important also to note is that the ΔCO_2 is also affected by the number of occupants (clients and technicians) in the room. The number of clients serviced differed between the formal and informal nail salons. From our observations, the formal nail technicians serviced, on average, more clients—almost twice the number serviced by the informal nail technicians—and, therefore carried out more nail applications.

For the purpose of comparison between the formal and informal sectors, and to adjust for overweighting the results of the relatively higher volatile VOCs, we developed the concept of adjusted TVOC where the selected VOC concentrations were adjusted for their specific evaporation rate. Adding all adjusted VOC concentrations

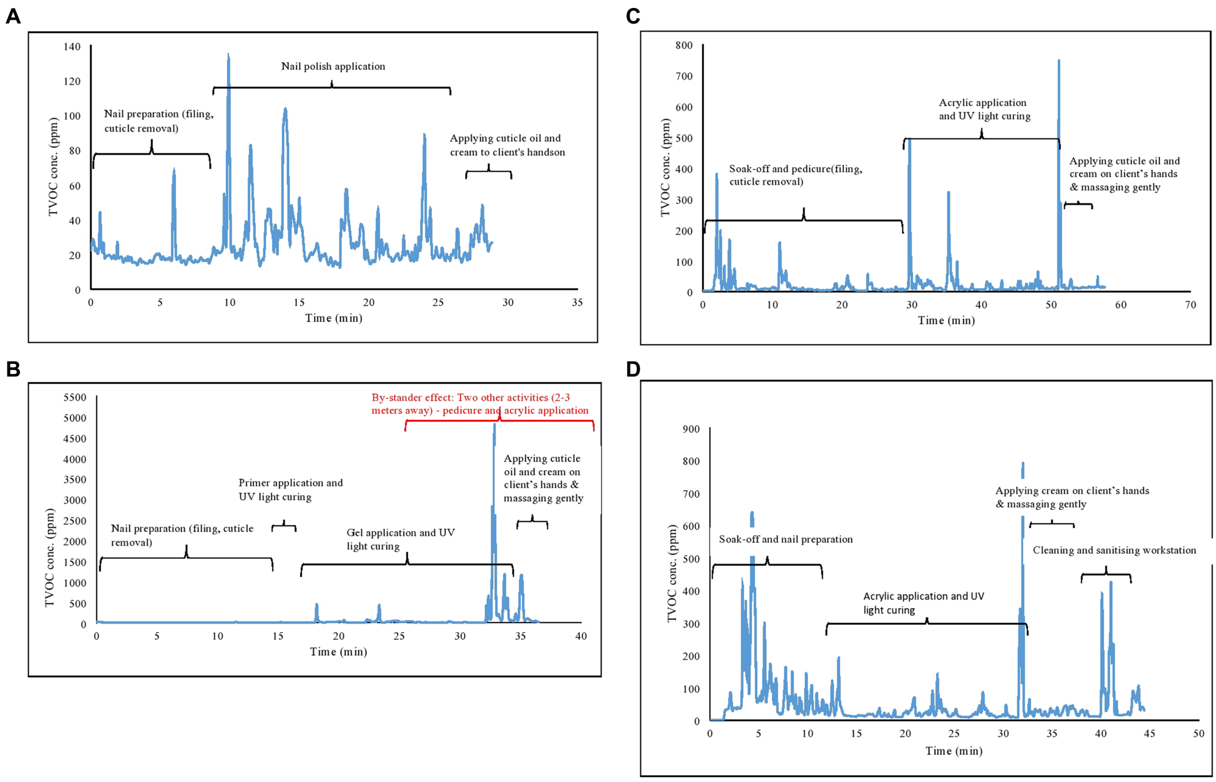

FIGURE 3
(A–D) Time profiles of peak exposure to volatile organic solvents (ppm) of various nail applications in the formal nail salons **(A)**: buff and paint; **(B)**: gel application; **(C)**: soak off, pedicure and gel application; **(D)**: soak off and acrylic application.

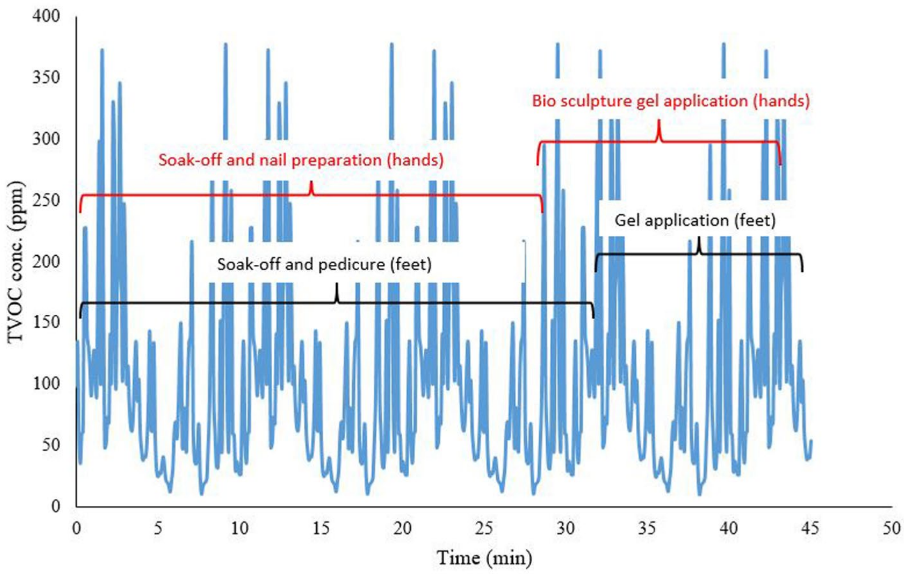

FIGURE 4
Time profile of peak exposure to volatile organic solvents (ppm) of soak off and bio sculpture gel application on hands and pedicure, simultaneously, in the formal nail salons.

resulted in an adjusted TVOC concentration as a metric for cumulative exposure to the VOCs detected and included in our analysis. Our approach, i.e., a surrogate d-limonene equivalent concentration, is quite comparable with the toluene-equivalent concentration as deployed by Wallenius et al. (31). Differences were noted in adjusted TVOC concentrations between the formal and informal nail salons, although not significant. The formal nail salons had a higher adjusted TVOC concentration than the informal nail salons. During the COVID-19 pandemic and the national lockdown restrictions, the informal nail salons experienced a reduction in the number of clients visiting their salons, resulting in fewer of clients serviced per day than the period before the pandemic, which could explain the large variation in VOC concentrations. The formal sector also had several nail technicians working in each salon (four to six), while most of the informal nail technicians worked alone or in pairs in a hair salon. Nail services performed by co-workers and associated VOC emissions in the formal nail salons may have contributed to the relatively high TVOCs (i.e., bystander exposure) with relatively low variation.

Of the 20 VOCs measured, 13 showed a DF of ≥30% above the limit of detection (LoD), similar to findings from other studies (3, 7, 12, 17–19). However, the measured concentrations were all below the respective South African occupational exposure limits (OEL), and the ACGIH threshold limit value (TLV). Acetone was detected at 100% DF in both the formal and informal nail salons with concentrations significantly higher among the formal nail technicians. Similarly high levels of acetone were measured in studies by Park et al. (7) and Ma et al. (4). Acetone is the main ingredient in nail polish removers and is used in all nail treatments to remove existing nail applications. The preferred method of soak-off may have contributed to the high concentrations of acetone in the formal sector and to the difference between the adjusted TVOC in the formal and informal sectors, since acetone was one of the VOC contributing the most to the shift-based TVOC concentrations. Between nail technician variations from the one-way ANOVA showed significant differences in acetone concentrations between nail technicians in the formal and those in the informal nail salons. Factors mentioned above, i.e., number of clients serviced, type of nail applications conducted, duration of the nail application, as well these the acetone soak-off method performed, played a role in these observed variations.

Methyl methacrylate was detected among the informal nail technicians and, to a far lesser extent, among the formal nail technicians. This may be attributed to the greater popularity of the acrylic nail application method among clients in the informal sector. Another contributing factor may be the use of products in the informal sector which still contain MMA. Small quantities of MMA have also been detected in some of the airborne VOC measurements in other studies (7, 17, 18, 32). Although the US-FDA has banned the use of MMA (22), in some countries, including South Africa, products containing MMA are still used (12, 16, 17).

Toluene, one of the ‘toxic trio’ (20) was detected in most of the formal and informal nail salons, but at low concentrations. Similar low concentrations have been detected in other studies (3, 4, 17–19). These low levels may be indicative of efforts to move towards ‘toxic trio’ free nail products (3).

n-Butyl acetate, an ingredient in nail polish and some nail polish removers, was detected at 100% DF for the formal nail technicians but at only 3.4% DF (1 observation) for the informal nail technicians. 2-propanol, was detected at 96.6% DF among the formal nail technicians and was the highest contributor, followed by acetone, to the adjusted TVOC for the formal nail technicians. This may be related to the frequency of nail applications conducted in the formal sector, using products that contain n-butyl acetate, as well as the practice of applying disinfectant (containing 2-propanol) during the nail preparation process (as observed in the formal sector). The method of applying nail polish remover during the soak-off, may also be a contributing factor.

The correlations between the VOCs themselves in the formal and informal sector is indicative of a relationship between the emissions and the type of application performed. The formal sector VOCs are most likely generated from the nail polish application and soak-off method, while informal sector VOC emissions are related to acrylic applications. The correlations between the number of clients and concentrations of three VOCs (ethanol, acetone, and ethyl methacrylate) were stronger in the informal than the formal sector. It can be assumed that the concentrations of the VOCs in the breathing zone of the informal technicians can be attributed primarily to emissions during the treatments. In the formal sector, VOC concentrations may be increased by emissions from other nail technicians simultaneously conducting treatments in the same space.

Task-based measurements (real-time TVOC measurements) for short-term peak exposures were conducted to provide additional exposure characteristics beyond the shift-based personal exposure measurements. High TVOC peaks were measured during nail applications that included soak-off at the beginning of the nail application process to remove existing nail polish. Acrylic applications emitted higher levels of TVOC concentrations than other nail applications. Some of the nail applications were conducted simultaneously (hands and feet). This saved time since two nail applications could be conducted at the same time, but exposure was potentially increased. There was also the “bystander exposure” effect where simultaneous applications were conducted. Since there was a co-worker conducting a pedicure and another conducting an acrylic application within 2 m, it is likely that the combined emissions contributed to the measured concentrations.

There were several limitations to our study. First, we used convenience sampling to select study participants. Consequently, we cannot generalize the results. However, we have shown that exposures to VOCs in the nail industry might be high enough to potentially cause adverse health effects. Second, the salon room occupancy was not monitored throughout the entire measurement period and thus occupants’ contribution to the CO_2 concentrations could not be determined. Since CO_2 concentrations are affected by both occupancy and ventilation, the differences in CO_2 concentrations alone have limited value as a proxy of room ventilation in the nail salons. Nevertheless, from observations, we believe that the increase in CO_2 during the day that was seen in the informal nail salons is indicative of a lack of proper ventilation. A third limitation is the sensitivity of the PID in characterizing individual VOCs. Only the individual 20 VOCs for the 8-h personal exposure measurements were identified, but these could not be directly used to determine the chemical composition of the vapors detected during the task-specific measurements. Lastly this study did not involve biological monitoring to determine the internal dose.

Regardless of these limitations, this is the first study to assess exposure to VOCs in the often-overlooked informal sector, and to compare exposures with the formal sector of the beauty industry. The combination of shift measurements and task-based measurements is particularly useful for providing an exposure profile in this under researched group of workers and identifying high-exposure tasks for targeted interventions.

5. Conclusion

The study findings highlight the potential exposures of informal sector workers in the beauty industry, which are often overlooked.

We found differences in the VOCs emitted from the nail products used, the nail applications performed, the number of clients serviced, and the VOC concentrations measured within the breathing zones of both the formal and informal nail technicians in this study. The formal nail salons had ventilation systems and more spacious rooms than the informal nail salons. More nail technicians worked in the formal nail salons at any one time, and more clients were serviced per salon, in comparison to the informal nail technicians. These factors played a role in the measured VOC concentrations and exposures: the formal nail technicians were exposed to higher TVOC concentrations, which may be due to the specific 'soak off' procedures used as well as 'background' emissions from their co-workers. The differences in the profiles of identified VOCs between the two sectors indicates the importance of the selection and procurement of 'safe' nail treatment products.

Studies of this nature are useful in developing intervention strategies to minimize exposure, such as informed decision making with regard to procurement of nail products, and adoption of safe work practices to reduce emissions from harmful chemicals among nail salon workers and their clients. The findings also inform policy development to help regulate these industries and ensure worker health and safety.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by University of the Witwatersrand Human Research Ethics Committee (HREC). The patients/participants provided their written informed consent to participate in this study.

Author contributions

GK, DB, and GN: conceptualization and design of the study. GK: literature review, original draft of manuscript, and data collection. GK, DB: data analysis and interpretation. DB and GN: critical review and editing of the manuscripts. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1147204/full#supplementary-material

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Appendix 4

Brouwer D, **Keretetse G,** Nelson G. Quantitative self-assessment of exposure to solvents among formal and informal nail technicians in Johannesburg, South Africa. Int J Environ Res Pub Health. 2023; 20:5459. Available from: https://doi.org/10.3390/ijerph20085459

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Quantitative Self-Assessment of Exposure to Solvents among Formal and Informal Nail Technicians in Johannesburg, South Africa

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Abstract: Participatory research, including self-assessment of exposure (SAE), can engage study participants and reduce costs. The objective of this study was to investigate the feasibility and reliability of a SAE regime among nail technicians. The study was nested in a larger study, which included exposure assessment supervised by experts, i.e., controlled assessment of exposure (CAE). In the SAE approach, ten formal and ten informal nail technicians were verbally instructed to use a passive sampler and complete an activity sheet. Each participant conducted measurements on three consecutive days, whereafter the expert collected the passive samplers. Sixty samples were, thus, analyzed for twenty-one volatile organic compounds (VOCs). The reported concentrations of 11 VOCs were converted into total VOC (TVOC) concentrations, adjusted for their respective emission rates (adj TVOC) to allow comparison within and between nail technician categories (formal vs informal), as well as assessment regimes (SAE versus CAE), using the data from the main study. In total, 57 SAE and 58 CAE results were compared, using a linear mixed-effects model. There were variations in individual VOC concentrations, especially for the informal sector participants. The major contributors to the adj TVOC concentrations were acetone and 2-propanol for the formal category, whereas ethyl- and methyl methacrylate contributed most to the informal nail technicians' total exposures. No significant differences in adj TVOC-concentrations were observed between the assessment regimes, but significantly higher exposures were recorded in the formal technicians. The results show that the SAE approach is feasible in the informal service sector and can extend an exposure dataset to enable reliable estimates for scenarios with substantial exposure variations.

Keywords: passive sampling; VOCs; participatory research

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1. Introduction

Citizen science, i.e., a voluntary collaboration among scientists and non-specialists to achieve both scientific and societal goals, is an emerging form of scientific inquiry that is growing in popularity in the environmental sciences [1,2]. Participatory knowledge generation is the main goal [1]. However, education and engagement of the public with scientific discoveries are other important objectives. Introducing citizen science into occupational health is considered a potentially innovative and economical approach, especially since resource constraints challenge this field [2]. From a measurement strategy perspective, daily monitoring of workers' exposure is the optimum approach. However, currently, the selection of an appropriate measurement strategy is a compromise between statistical efficacy, i.e., minimizing the variance of an unbiased estimate of the target exposure variable, and associated costs [3]. Traditionally, in occupational exposure assessment, much attention is paid to generating high-quality data with high chemical analytical precision and accuracy, requiring highly skilled experts and high-precision devices. However, Nicas et al., (1991) have demonstrated that measurement error is often small relative to the environmental variability of concentrations in the workplace [4]. Therefore, efforts were taken to reduce sampling costs, for example, by employing passive, instead of active, sampling [5]. Another approach to reducing the cost of exposure sampling was introduced by Liljelind and co-authors in the early to mid-2000s [6–8], and this was later explored by others [9–11]. The concept of self-assessment of exposure (SAE) implies that workers assess their own exposures, instead of occupational hygienists. The basic idea was that an extension of the number of data points could be achieved without additional (researcher) costs. Quantitative self-assessment of inhalation exposure relied mainly on passive sampling of volatile organic compounds (VOCs) and gases. Hertsenberg et al., (2006) reported the results of a quantitative study on VOC exposure amongst shoe repair men, using two different regimes of self-assessment, i.e., different levels of expert supervision [9]. The group with the lowest level of supervision received only written instructions on the use of the passive samplers (diffusion badges), whereas participants in the other group received extensive oral instructions, followed by controlled assessment of exposure. Petterson et al., (2008) conducted a study among sawmill workers, aiming at the relationship between measurement frequency of terpenes, variation of concentrations using diffusive samplers, and workers' propensity to perform exposure measurements [10]. Workers were instructed both in written form and orally. The number of sampling days was not prescribed, but it was decided by the individual worker. No supervised measurements were conducted in this study. Hedmer et al., (2017) applied self-assessment of exposure for tunnel construction workers [11]. Workers received written instructions on handling the passive samplers (diffusion tubes) to assess exposure to NO_2. A second, randomly selected group of workers, performing the same tasks, was monitored under the supervision of an occupational hygienist. Although the reliability of SAE data varied between the studies, it was concluded that workers, if well instructed and motivated, can generate reliable exposure measurements. Silicone wristbands have recently been deployed as personal passive sampling devices to assess dermal and inhalation exposure to various VOCs, semi-volatile organic compounds (SVOCs), and pesticides [12]. The use of wristbands was also piloted in nail salons to sample SVOCs. However, they were not used a self-assessment tools [13].

To investigate the reliability of SAE, especially in the informal service sector, we report on the results of a self-assessment study in which nail technicians in both formal and informal nail salons measured inhalation exposure to VOCs using passive diffusion samplers. Therefore, we compared the central tendency of VOC exposure concentrations of a SAE nail technician group with a group of nail technicians for which exposures were measured under the conventional controlled assessment of exposure (CAE) regime.

2. Materials and Methods

2.1. Study Population

This comparative study had a cross-sectional design and was nested in a larger study in nail salons in the City of Johannesburg [14], hereafter referred to as the controlled assessment of exposure (CAE) study. Convenience sampling was used to select ten nail salons, representing the informal sector, as well as six salons, representing the formal sector, assuming that 30 samples for each sector and exposure assessment regime would be sufficient to demonstrate differences for a hypothesized moderate effect size of 0.48. The formal nail salons were franchises of one of the largest local beauty therapy companies in South Africa, which permitted them to approach the salons in the northern suburbs of Johannesburg. The informal nail salons comprised unregistered nail salons in the central Johannesburg Braamfontein area, some of which operated inside hairdressing salons. Before the exposure assessment was conducted as part of the main study, salons were visited, the purpose of the study was explained, and the nail technicians were invited to participate. Nail technicians who also performed hair and other cosmetic treatments, and those involved in other activities outside work, which may generate the release of solvents, were excluded from the study.

All nail salons in this study offered essential nail services, including manicures and pedicures, as well as nail polish, gel, and acrylic applications. Most nail applications began with an acetone soak-off process to remove old nail applications. The most common applications in the formal and informal nail salons were gel and acrylic nail applications, respectively. All the formal nail salons used similar products from known brands, procured through a structured company system. In the informal nail salons, such a central procurement system was lacking. In formal salons, four to six nail technicians usually offered nail treatment services simultaneously; in informal salons, only a single technician, or two nail technicians, worked simultaneously with a hairdresser, in most cases. Further details on the nail technicians and the nail salons are reported elsewhere [14].

If a nail technician agreed to participate in the study, i.e., to self-assess their personal exposure on three consecutive workdays, oral instructions were given on how to open, attach, close, and store the passive samplers (diffusion tubes), as well as how to complete the worksheets. The worksheets facilitated the participant to record information, such as the time the passive sampler was opened and donned, the number and types of nail applications performed, and the duration of the nail applications. In most cases, the instructions were given on a Monday, and the sampling was conducted on Tuesday through Thursday afternoon, after which the samples were collected. Finally, the researcher checked and noted the sampling tubes' status and the worksheets' completeness. Where information was missing, attempts were made to retrieve this from the participants.

Ten nail technicians from both formal and informal sectors were included in the self-assessment study, resulting in 30 measurements for each sector. Unfortunately, COVID-19 restrictions resulted in a time gap between the self-assessment and the controlled-assessment of the main study. The self-assessment of the informal sector was conducted in June 2021, whereas the other sampling campaigns were conducted in the last quarter of 2021. Consequently, it was difficult to recruit the same technicians from the main study (controlled assessment) into the self-assessment study due to business closures and dismissals. Only eight nail technicians, i.e., four from each sector, participated in both assessments.

2.2. Exposure Assessment

Personal exposure measurements were collected using diffusion/passive samplers (Radiello® Passive sampler, Sigma Aldrich, Kempton Park, South Africa). Before sampling, the sorbent cartridge was removed from its glass storage tube and inserted into the diffusive body; whereafter, it was attached to the participant's lapel. Sampling devices were deployed to measure exposures for at least 80% of the work shift over three consecutive days, for each nail technician. A total of 60 personal exposure measurements in the formal (n = 30) and informal (n = 30) nail salons were collected. Field blanks were also collected during the controlled assessment to check for contamination during transport. At the end of the sampling period, the participant detached the sampler from the lapel, placed it in the glass tube, capped and labelled it, and stored it at <5 °C until it could be analyzed. The same procedure was followed during the controlled assessment; however, the investigator attached and removed the sampler and recorded the nail applications, etc.

2.3. Chemical Analysis

Details of the chemical analysis have been published elsewhere by Keretetse et al. [14]. In brief, after extraction of the sorbent tubes in CS_2, gas chromatography with a flame ionization detector was used to quantify the concentrations of VOCs. Chromatographic separation was performed using a DB-624 column (0.25 mm ID, 30 m length, 1.4 µm film thickness) for quantification, as well as a DB-WAX column (0.25 mm ID, 30 m length, 1.5 µm film thickness) for verification, with a split injection of 3 µL and split flow of 20 mL/min. The carrier gas was nitrogen at a constant pressure of 5 psi. The injector temperature was 220 °C, and the detector temperature was 200 °C. The MSD ChemStation macro program extracted Peak areas, adjusted for internal standards, and transferred them to an Excel spreadsheet. The average concentration over the exposure period was calculated from the mass of the analyte found on the cartridge and the reported duration of sampling.

Based on a review of the literature and the information obtained from the labels of the products used, or the safety data sheets (SDS) or the ingredients list (if any), 21 VOCs were analyzed. The samples (batches) collected during the informal sector self-assessment were sent to the laboratory for analysis much earlier than the batches with other samples. Unfortunately, only 15 similar VOCs were common in both batches. To simplify the calculation, the analytical limit of detection (LoD) and limit of quantification (LoQ, 3.3 times LoD) for all compounds were set to 0.50 μg/mL and 1.65 μg/mL, respectively.

2.4. Data Analysis

Data pre-processing, including data cleaning and visualisation, was conducted using Microsoft Excel 2016. Descriptive statistics were calculated using ExpoStats, a Bayesian toolkit [15]. Imputation for data below LoQ was performed using Expostats—a NDexpo /RoS tool. NDexpo implements a rigorous censored data treatment method by labelled regression on order statistic [16]. For the data in the present study, the analytical LoQ was converted into a LoQ sampling concentration of 0.033 mg/m^3. Since measured exposure concentrations appeared to be lognormally distributed, all statistical analyses were conducted on ln-transformed concentrations. Eleven VOCs, with a detection frequency of $\geq$30%, were selected from the 21 reported VOCs for further statistical analysis.

Since both the number and the type of VOC varied within and between the sectors, the so-called adjusted total VOC concentration (TVOC) was calculated to enable comparison. The adjTVOC is defined as the total of the selected VOCs' concentrations per subsector, each corrected by their respective evaporation rate relative to the lowest evaporation rate of the selected VOC, i.e., d-limonene (Appendix A Table A1). The evaporation rates were calculated using Hummel's equation, which was incorporated into the IHMod^{TM} 2.0 mathematical model supporting files [17]. The equation requires only the molecular weight, vapour pressure, air velocity, pool size, ambient pressure, and liquid temperature, or estimates of these quantities, to approximate the overall evaporation rate in mass/time/unit area. The ratio of the evaporation rate of each VOC to that of d-limonene was used to correct the concentration of each individual VOC in what is referred to as the weighted concentration. The sum of these individual VOC-weighted concentrations was the adjusted TVOC concentration in mg/m^3.

JASP (JASP Team, version 0.16.3) [18] was used the estimate the effect of the exposure assessment regime, i.e., the self-assessment of exposure (SAE) and controlled-assessment of exposure (CAE), with a mixed linear effect model. In the model, the natural logarithm of the adjusted TVOC-concentration is the dependent variable, whereas the assessment regime (SAE or CAE), as well as the sector category (formal or informal), are the fixed effects. Both the participant and the day of measurements represent the random effects. The model was fitted using maximum likelihood, and random effects are assumed to be statistically independent. The model can be described as follows.

$$Y_{ijrcd} = \beta_0 + \beta_r + \beta_c + \alpha_i + \alpha_j + \varepsilon_{ijrc} \tag{1}$$

where Y_{ijrcd} = the ln-transformed TVOC concentration of the i-th worker, measured on the j-th day, under the assessment regime r in the category c; β_0 denotes the intercept, whereas β_r and β_c represent the fixed effects of the assessment regime and the category, respectively. The random effects of the worker and the sampling day are represented by α_i and $\alpha(_j)$, respectively. ε_{ijrc} denotes the random error. The nonparametric Wilcoxon signed-rank test was used to test differences between the two assessment regimes, based on the GSDs for the same VOC.

3. Results

Nearly all formal nail technicians completed data capture sheets. If any data were missing, such as the number of clients or type of treatments, this information was retrieved from the client registration system when the researcher collected the forms and the samplers.

In contrast, since such a system was lacking for the informal nail technicians, 15 data sheets were missing from five nail technicians.

Twenty-one VOCs were analyzed in total; however, only 15 VOCs from the SAE regime in the informal sector were analyzed. This included 1-butanol, which was not analyzed for all the other groups. Table 1 shows the analyzed VOCs and the samples with values >LoQ.

Table 1. Summary of VOCs analyzed and identified (>LoD) during SAE and CEA sampling campaigns.

VOC	Formal				Informal			
	SAE (n = 30)		CAE (n = 29)		SAE (n = 30)		CAE (n = 29)	
>LoQ	n	%	n	%	n	%	n	%
Acetone	28	93	29	100	29	97	29	100
Benzene	5	17	x	17	9	31	n.a.	n.a.
1-Butanol	n.a.	n.a	n.a	n.a	n.a.	n.a.	11	38
n-Butyl acetate	29	97	29	100	3	10	1	3
Chloroform	0	0	0	0	7	23	9	31
Ethyl acetate	29	97	29	100	29	97	24	83
Ethyl benzene	3	10	2	7	3	10	0	0
Ethanol	30	100	29	100	25	83	28	97
Ethyl methacrylate	30	100	26	90	28	93	24	83
d-limonene	27	90	28	97	11	37	13	45
Methyl ethyl ketone	7	23	3	10	n.a.	n.a.	1	3
Methyl-methacrylate	0	0	1	3	27	90	25	86
Methyl-isobutyl ketone	0	0	0	0	n.a.	n.a.	0	0
Perchloroethylene	1	3	n.a.	n.a.	1	3	n.a	n.a.
1-propanol	1	3	4	14	10	30	6	20
2-propanol	30	100	29	100	n.a.	n.a.	7	24
Propyl acetate	22	73	18	62	n.a.	n.a.	3	10
Toluene	29	97	28	97	18	60	26	90
Trichloroethylene	0	0	0	0	n.a.	n.a.	0	0
White spirits	25	83	24	83	26	87	27	93
Xylene	1	3	3	10	8	27	10	34

n.a.: not analyzed.

From the 21 VOCs reported, 11 showed a detection frequency of >30% of the limit of detection (LoD) within the same sector. Methyl-isobutylene-ketone (MIBK) and trichloroethylene were not detected in any sample, whereas chloroform was detected only in the informal sector. Although benzene was detected in some samples, the concentrations were close to LoQ. Field blanks, which were collected and analyzed at each salon, showed negligible VOC levels, confirming that transport, storage, and handling activities did not contaminate the sampling badges. Based on the percentages detected, the 11 VOCs were selected for further analysis, i.e., acetone, n-butyl acetate, ethyl acetate, ethanol, ethyl methacrylate, d-limonene, methyl-methacrylate, 2-propanol, propyl acetate, toluene, and white spirits (Table 2). For the SAE in the informal sector, three results were excluded from further analysis; two resulted from a shorter-than-optimal duration of monitoring (<3 h), and one result showed concentrations of all VOCs below the LoD. During the CAE, 59 personal exposure measurements were collected, as one informal study participant was not present for work on the third assessment day. Since the results for one formal nail technician were all below LoD, this sample was excluded. Hence, 58 CAE- and 57 SAE-sampling results were further analysed.

Table 2. Summary statistics of the VOC shifts in average concentrations (mg/m^3), which were selected for further analysis.

VOC	Formal						Informal					
	SAE (*n* = 30)			CAE (*n* = 29)			SAE (*n* = 27)			CAE (*n* = 29)		
	GM	GSD	IQR	GM	GSD	IQR	GM	GSD	IQR	GM	GSD	IQR
Acetone	65.7	6.63	54.4–169	108	2.49	64.7–162	10.9	8.67	3.3–56.7	24.3	5.11	11.3–78.7
n-Butyl acetate	0.59	2.11	0.33–0.87	0.62	1.97	0.41–0.96	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ethyl acetate	1.73	2.03	1.15–2.78	2.01	1.72	1.46–3.13	0.102	6.41	0.027–0.393	0.21	5.4	0.08–0.58
Ethanol	3.39	1.69	2.54–5.31	3.88	1.58	3.16–5.01	1.72	5.65	0.77–4.41	2.34	4.41	1.19–5.5
Ethyl methacrylate	1.49	4.33	0.62–3.4	1.56	6.94	0.39–5.67	6.24	8.18	2.08–29.3	3.57	14.9	0.35–32.8
d-limonene	0.19	2.79	0.12–0.28	0.14	2.63	0.09–0.21	0.0298	2.55	0.02–0.06	0.03	7.06	0.005–0.08
Methyl-methacrylate	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.89	18.3	0.135–23.7	8.06	9.48	2.41–54.5
2-propanol	46.7	2.21	28–91.5	43.7	1.72	33.8–58	n.a.	n.a.	n.a	n.a.	n.a.	n.a.
Propyl acetate	0.0469	2.32	0.03–0.07	0.0439	2.17	0.03–0.07	n.a.	n.a.	n.a	n.a.	n.a.	n.a.
Toluene	0.06	2.34	0.03–0.14	0.04	1.78	0.03–0.06	0.0372	2.01	0.0218–0.061	0.04	1.54	0.03–0.04
White spirits	0.94	5.96	0.2–3.41	0.45	4.76	0.1–1.19	1.02	5.11	0.27–3.39	0.9	2.46	0.49–1.67
Average		3.24			2.78			7.11			6.29	

n.a.: not applicable.

Table 2 shows that, for the formal sector, both the SAE and CAE regimes revealed that the VOCs with the highest concentrations were acetone and 2-propanol. The GM of the acetone concentrations was 65.7 and 108 mg/m^3 for the SAE and CAE, respectively, with a much higher GSD (6.63) for the SAE compared to the CAE regimen (2.49). The GMs of the 2-propanol concentrations for the two assessment regimes were much closer, i.e., 46.7 versus 43.7, with a higher GSD for the SAE compared to the CAE, i.e., 2.21 versus 1.72. This demonstrates a general trend, wherein the GSDs of the VOC concentration distributions were slightly higher for the SAE regime, although they were not statistically significant ($p = 0.064$).

In the informal sector, acetone was also the VOC with the highest concentrations during both regimes. During the SAE regime, concentrations of ethyl-methacrylate and methyl-methacrylate showed the second-highest and third-highest GM, respectively, where the order was swopped during the CAE regime. The concentration distributions showed very large GSDs for both these VOCs. No statistically significant differences were observed in the GSD for all VOCs for both assessment regimes ($p = 0.55$).

The major contributors to the adjusted TVOC concentrations are depicted in Figure 1. For the formal sector, the adjusted TVOC was dominated by 2-propanol and acetone, whereas methacrylates were the main contributors in the informal sector. The picture for both regimes per sector is similar. The adjusted TVOC concentration distribution per sector and assessment regime is depicted in Figure 2. The mixed effects model estimates are shown in Table 3. Analyses were based on ln-transformed data, and the model results were back-transferred. The grand total of observations showed a significant difference in the restricted maximum estimates of the GMs for both sectors ($p = 0.011$); however, the effect of the assessment regime was not statistically significant ($p = 0.37$).

Table 3. Restricted maximum likelihood estimates of the geometric mean (GM) exposure to adj TVOC in the formal and informal sector, separately and averaged, over the level of assessment regime ($N_{formal} = 59$, $N_{informal} = 56$). CI, confidence interval. The asterisk indicates a statistical significance difference.

Category	*n*	GM (mg/m^3)		
		Estimate	Lower 95% CI	Upper 95% CI
Formal total	59	8.3 *	6.0	11.6
Informal total	56	3.6 *	2.4	5.3
Formal CAE	29	8.53	5.32	13.66
Formal SAE	30	8.17	5.74	11.64
Informal CAE	29	4.27	2.65	6.88
Informal SAE	27	3.08	2.07	4.59

* $p = 0.011$.

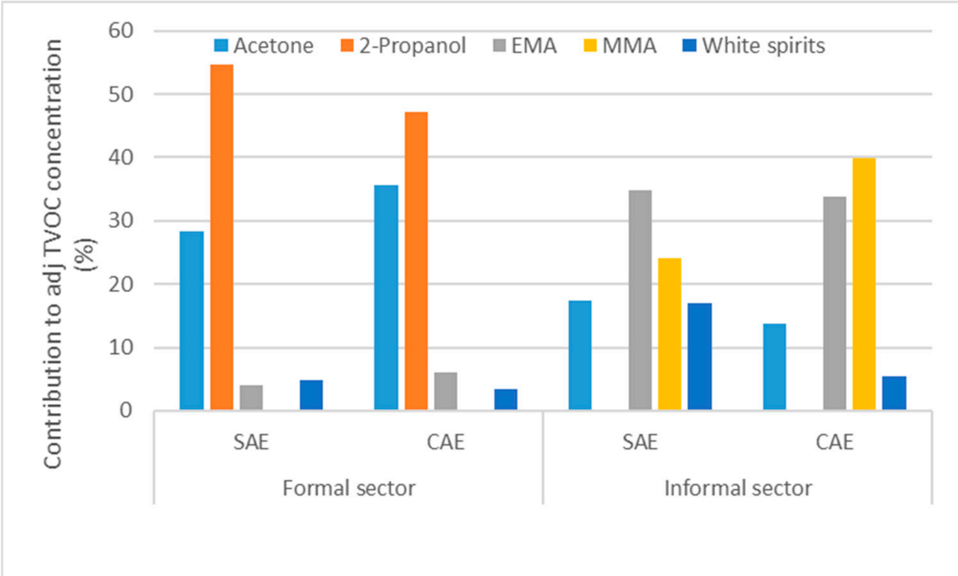

Figure 1. Major contributors to the adjusted TVOC-concentration (%) for both sectors and assessment regimes: SAE: self-assessment of exposure, CAE: controlled assessment of exposure. EMA: ethyl-methacrylate; MMA: methyl-methacrylate.

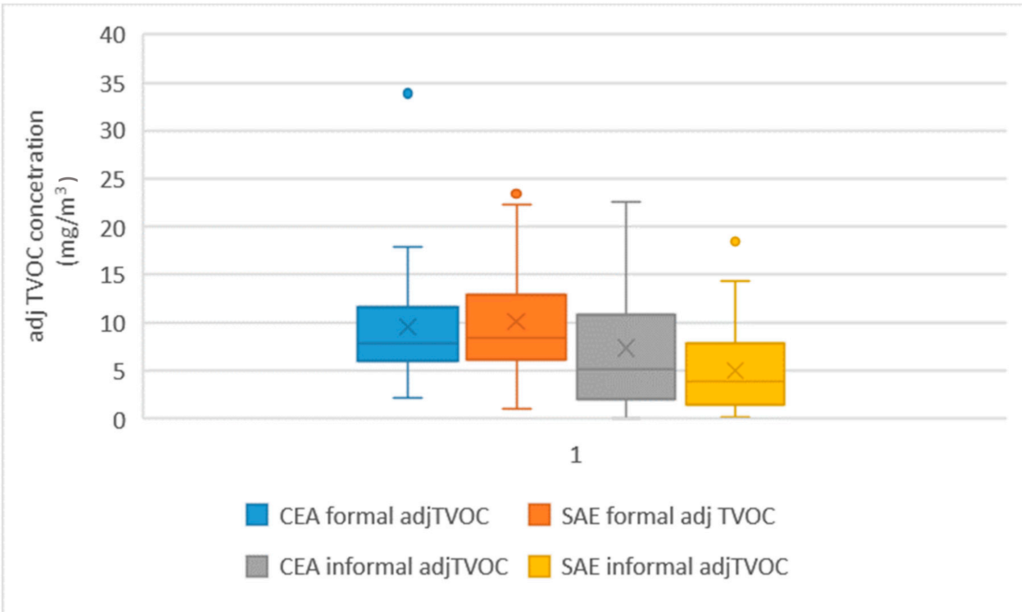

Figure 2. Box-plots of adjusted TVOC-concentrations (mg/m^3) for both exposure assessment regimes. The dots represent the outliers.

4. Discussion

Nail treatments require the use of various products, depending on the type of treatment. As was demonstrated by Keretetse et al. [14], the type of treatment demands different products. Therefore, a nail technician's exposure to VOCs will heavily depend on the number of clients and treatments performed. Consequently, large exposure variances are expected, as demonstrated by substantial GSDs for most of the VOCs. In our previous paper, we showed that, due to bystander exposure, the variation in exposure levels of the nail technicians in the formal sector was smoothed [14]. In contrast, the informal technicians' personal VOC exposure was determined entirely by their own activities. For example, the exposure to methacrylates is associated with artificial nail treatments, and Table 2 shows that, especially for the informal sector, the GSDs of the methacrylates' concentrations were large. The variability of exposure to these VOCs during the SAE assessment regime was enhanced by 'slow business', immediately following the lifting of stringent COVID-19 restrictions. Unfortunately, the information on the number of clients and types of treatments was missing for half of the informal SAE participants. Soaking off residues from previous nail treatments is part of every treatment, with acetone being the major VOC. Remarkable is the high frequency and the relatively high concentration of 2-propanol in the formal sector. This VOC is also a constituent of hand sanitizer, an important part of the COVID-19 non-pharmaceutical intervention protocols to which strict adherence was observed in the formal sector.

To enable comparison and to adjust for overweighting the results of the relatively higher volatile VOCs, we developed the concept of VOC–concentration, adjusted for the VOC-specific emission rate. Adding all adjusted VOC–concentrations resulted in an adjusted total VOC–concentration as a metric for cumulative exposure to the VOCs detected and included in our analysis. This differs from other approaches where TVOC was reported as the sum of the concentrations of compounds detected in the range of C_6–C_{16} [19], or in the form of a VOC score [9]. Our approach, i.e., a surrogate d-limonene equivalent concentration, is quite comparable with the toluene-equivalent concentration, as deployed by Wallenius et al., (2022) [20].

This study aimed to investigate whether self-assessment of exposure could reliably estimate the true distribution for the nail technicians under investigation. Our results indicate that the different exposure assessment regimes did not significantly affect the exposure assessment results. Consequently, the results of both CAE and SAE could be pooled, revealing a significant difference in the adjusted TVOC concentrations between both categories. Whereas, based only on the CAE or SAE data, no statistically significant differences between the formal and informal nail technicians were observed. Our results, regarding the performance of SAE compared to CAE, are aligned with the results and conclusions of other quantitative studies of self-assessment exposure with similar designs.

In the study reported by Hertsenberg et al., (2006), the authors found no significant differences in the sum score for VOCs. However, the exposure variability appeared to be significantly higher for the group that received written instructions. The comparison of the CAE and SAE within the group that received face-to-face instructions showed no differences in either the GM or the exposure variability.

The study by Hedmer et al., (2017) revealed that there were no statistically significant differences in the mean exposures observed between the controlled and the self assessment groups. The authors concluded that, by employing SAE, more workers could be included in the study, especially under the harsh work environment conditions of the tunnel construction workers and limited accessibility to the (tunnel) workplace for experts to conduct the measurements [11]. Since the study reported by Pettersson et al., (2008) had a different aim, i.e., to investigate whether the average and variation in exposure levels were of importance in the workers' performance of exposure measurements, the authors reported the correlation between each worker's number of measurements and their mean exposure levels and the coefficient of variance, respectively [10]. No statistically significant correlations were found. An interesting finding was that, in all four workplaces included in the study, the supervisor, contrary to the instructions, organized the measurements. Therefore, the authors concluded that a formal organizational structure is needed for systematic monitoring beyond letting the workers conduct a simple SAE.

Several limitations could have affected the results of our study. Environmental conditions, e.g., temperature and relative humidity, were not recorded during the SAE measurements. Since all CAE measurements and the SAE measurements in the formal sector were performed on three consecutive days in the early summer period (October 2021), the average temperature ranged only from 23 to 28 °C [14]. As reported, the SAE for the informal sector took place during the winter period (June 2021). Hence, we expect somewhat lower average temperatures over the workday. However, it is unclear what the impact of temperature on the VOC concentrations might have been. On the one hand, lower temperatures will decrease volatilization, whereas, on the other hand, less ventilation by keeping the door closed might have increased the VOC concentrations. In our calculation of the TVOC concentration for the comparison between SAE and CAE, we considered only the VOCs detected in 30% or more samples for both regimes. Consequently, we excluded the results for ten VOCs, including benzene, chloroform, and xylene. This hampers interpretation according to health risk. It also affected the comparison between the formal and the informal sector, as ten and eight VOCs were included in the TVOC calculations for the formal and informal sectors, respectively. Importantly, the fact that 2-propanol was not analyzed in the informal sector during the SAE regime impacts the comparison between the two sectors, as 2-propanol contributes most to the adjusted TVOC concentration in the formal sector. However, the results for 2-propanol for the CAE in the informal sector showed a low detection frequency and relatively low concentrations of 2-propanol, as reported by Keretetse et al. [14]. In contrast, the omission of the 2-propanol did not affect the comparison of the SAE and CAE regimes within the formal sector. Another limitation of our study is the time gap between the self-assessment in the informal sector and the other sampling campaigns. The samples of the SAE in the informal sector were analyzed separately from the others. They were affected by decisions on the particular VOCs to include, as well as the slightly different LoDs. We tried to compensate for this by deploying the same LoD/LoQ for all sampling results, but this is arbitrary. Another drawback of the study is the lack of contextual information relevant to understanding the exposure results. As demonstrated previously [14], the number of clients, type of nail treatment, and bystander operations are important determinants of exposure. The poor completion of time/activity sheets, especially in the informal sector, seems an inherent drawback of self-assessment studies and does not generate valuable information to understand the exposure process. Passive sampling, requiring offline analysis, still needs interpretation and feedback from researchers. This limits the use of this method as a citizen science tool due to the lack of information regarding an association between exposure and participants' behavior. In contrast, direct reading devices or wearable low-cost sensors could provide this type of information that could have an impact on the wearers' behavior, thus reducing exposure [21], and they may be more cost-effective than traditional expert-supervised active sampling devices [22,23]. A technical limitation regarding diffusion samplers is that the badge or tube should be placed on the participant's lapel without any obstructions, and this should be performed for a sufficient time. Since the diffusion rate is determined by concentration differences, a recently opened passive sampler that is not worn, or that is worn for a short period, will generate biased results. In our study, we used a cutoff for a sampling duration of three hours, but the results might still be inaccurate. Future SAE and citizen science studies will benefit from the further development of various wearable low-cost sensors that provide not only estimates of pollutants' concentrations, but also complementary information to evaluate the results from the perspective of exposure assessment [24].

Despite the limitations, the results of the study demonstrate that, especially in cases with exposure scenarios where there are large concentration variances, an increase in the number of samples provides a better estimate of the central tendency, even though the SAE regime may generate 'low-quality' data compared to the CAE. Our findings support the conclusion by Nicas et al., (1991) that the analytical variability, or the quality of the measurement, contributes minimally to the total measurement variability, especially in scenarios with GSDs > 2 [4].

5. Conclusions

Self-assessment of exposure in occupational settings, including informal workplaces, seems to be a feasible and economical method to contribute to the expansion of exposure data, which enables a more reliable interpretation of exposure variation. In principle, SAE can be a citizen science tool in occupational health; however, passive sampling, requiring analytical costs and experts' feedback, is not the ideal method to assess exposure.

However, exposure science approaches and expertise to identify the exposure pathway and determinants of exposure are still needed to develop effective exposure control strategies.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Weighting factors of VOCs used to calculate adjusted TVOC concentrations.

Compound	Evaporation Rate (mg/min) *	Ratio d-Limonene	Relative Weight to the Lowest Evaporation Rate
Ethanol	37,600	17.49	0.06
Acetone	136,000	63.26	0.02
Ethyl acetate	75,600	35.16	0.03
Methyl methacrylate	32,600	15.16	0.07
Ethyl methacrylate	25,300	11.77	0.08
Propyl acetate	28,000	13.02	0.08
Toluene	26,100	12.14	0.08
n-Butyl acetate	11,200	5.21	0.19
d-Limonene	2150	1.00	1.00
2-Propanol	24,900	11.58	0.09
White Spirits	6880	3.20	0.31

* calculated using Hummel's equation (see text).

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Appendix 5

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24 April 2023

Dear Ms Keretetse

Request to include your paper, published in *Occupational Health Southern Africa*, in your PhD thesis

Permission is hereby granted for you to include your paper, 'Evaluating awareness of health risks and self-reported symptoms among nail technicians in Johannesburg, South Africa – a pilot study', published in Vol. 28, No. 6 of *Occupational Health Southern Africa,* in your PhD thesis.

Yours faithfully

Kevin Beaumont

Publisher: *Occupational Health Southern Africa*

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Appendix 6

Questionnaire

Questionnaire

Title: Occupational exposure to chemicals, and health outcomes, among nail technicians in Johannesburg, South Africa.

Demographic information							
1. Subject number/code:							
2. Date:							
3. Age:							
4. Sex:		**Male**			**Female**		
5. What is your current occupation? ***(Please tick the appropriate box)***							
Nail technicians		**Beauty therapist**		**Hairdresser**		**Other: (Specify)**	

6. Do you have other sources of income other than your current job? ***(Please tick the appropriate box)***	**Yes**	**No**
If so, what are they?		
7. How long have you been working in this current job?		
8. What was your previous job?		
9. How many clients do you see per day in your current job?		

10. How many hours per day do you work? ***(Please tick the appropriate box)***			
6 hours/day		12 hours/day	
8 hours/day		Other	

11. How many days per week do you work? ***(Please tick the appropriate box)***	
5 days/week	
6 days/week	
7 days/week	
Other	

Work practices and perception of health risks					
12. What type of nail applications do you perform and how often? ***(Please tick the appropriate box)***	**Type of Nail application performed**	**Every day**	**Once a week**	**Once a month**	**Once every 3 months**
Buff and paint					
UV gel/gelish					
Acrylic method					
All of the above					
13. What type of nail products do you use and how often? ***(Please tick the appropriate box)***	**Type of Nail Product used**	**Every day**	**Once a week**	**Once a month**	**Once every 3 months**
Nail polish					
Nail polish remover					
Liquid and powder acrylic					
UV gel					
Primer					
Nail tips glue					
Artificial nail tips remover					
All of the above					
14. Have you ever read the label of these nail products? ***(Please tick the appropriate box)***				**Yes**	**No**
15. Do you know the names of the chemicals contained in nail products that you use? ***(Please tick the appropriate box)***				**Yes**	**No**
Acetone					
Ethanol					
Ethyl acetate					
Ethyl methacrylate					
Methyl methacrylate					
n-Butylacetate					
Toluene					
Xylene					

Dibutyl phthalate		
Formaldehyde		
Isopropyl acetate		
Titanium dioxide		

16. How harmful do you think these nail products are? ***(Please tick the appropriate box)***	**Not at all**	**Slightly**	**Moderately**	**Extremely**
Nail polish				
Nail polish remover				
Liquid and powder acrylic				
UV gel				
Primer				
Nail tips glue				
Artificial nail tips remover				

17. Have you received any training on the effects of these nail products and chemicals? ***(Please tick the appropriate box)***	**Yes**	**No**
If yes then how long was the training?		

18. Do you take any steps to protect yourself from the effects of these chemicals? ***(Please tick the appropriate box)***	**Yes**	**No**

19. If yes, how do you protect yourself? ***(Please tick as many as applicable)***	
Extraction ventilation (ceiling extraction fan, table extraction fan, etc.)	
Dilution ventilation (opening doors)	
Use gloves	
Use mask	
Use goggles	
Avoid skin contact	
Put lids on containers	
Keep lids on containers	

Decant products into smaller pots	
Good hygiene	
Use product as instructed	
20. If not, is there a reason why you don't? ***(Please tick as many as applicable)***	
Not needed	
Products are safe	
Product considered low risk	
No fumes with this product	
Has never caused harmed before	
Mask gets in the way	
Mask uncomfortable/off-putting	
Difficulty using gloves	
Nothing to protect ourselves with	
No reason	

21. Have you experienced any ill-health symptoms since working as a nail technician? ***(Please tick the appropriate box)***	**Yes**	**No**

22. If yes, which ill-health symptoms have you suffered from? ***(Please tick as many as applicable)***		
Symptom 1	Headaches	
Symptom 2	Light-headedness	
Symptom 3	Difficulty breathing	
Symptom 4	Chest tightness	
Symptom 5	Regular cough	
Symptom 6	Wheezing	
Symptom 7	Nasal congestion	
Symptom 8	Doctor diagnosed asthma	
Symptom 9	Throat irritation	
Symptom 10	Nose irritation	

Symptom 11	Eye-irritation	
Symptom 12	Skin problems (dryness, scaling, rash, redness)	
Symptom 13	Eczema	
Symptom 14	Neck pain	
Symptom 15	Shoulder pain	
Symptom 16	Wrist and hand pain	
Symptom 17	Upper back pain	
Symptom 18	Lower back pain	
Symptom 19	Leg or feet pain	

23. Have you suffered from any of the following ill-health symptoms in the last 4 weeks?
(Please tick the appropriate box)

Symptom	**Yes**	**No**	***Symptom***	**Yes**	**No**
Symptom 1			*Symptom 11*		
Symptom 2			*Symptom 12*		
Symptom 3			*Symptom 13*		
Symptom 4			*Symptom 14*		
Symptom 5			*Symptom 15*		
Symptom 6			*Symptom 16*		
Symptom 7			*Symptom 17*		
Symptom 8			*Symptom 18*		
Symptom 9			*Symptom 19*		
Symptom 10					

24. Do any of these symptoms get better when you are away from work for more than one day?
(Please tick the appropriate box)

Symptom	**Yes**	**No**	***Symptom***	**Yes**	**No**
Symptom 1			*Symptom 11*		
Symptom 2			*Symptom 12*		
Symptom 3			*Symptom 13*		
Symptom 4			*Symptom 14*		

Symptom 5			*Symptom 15*		
Symptom 6			*Symptom 16*		
Symptom 7			*Symptom 17*		
Symptom 8			*Symptom 18*		
Symptom 9			*Symptom 19*		
Symptom 10					

Appendix 7

Data Capture Sheet

Data Capture Sheet

SAMPLE INFORMATION			
DATE:		SAMPLE NO.:	
PARTICIPANT NO:		EQUIP NO.:	
OCCUPATION:		SAMPLE TYPE	PERSONAL / TASK BASED
SHIFT	From: / To:	SAMPLING MEDIA:	

APPLICATION PERFORMED:	DURATION (PER CLIENT)	NUMBER OF CLIENTS
Basic Mani/Pedi		
Buff and paint		
UV gel/gelish		
Acrylic		
Other (specify) ……………………		

SAMPLE TIME (MIN)	
TIME ON	
TIME OFF	
TOTAL	

EVALUATION OF CONTROLS		
PPE USED (YES/NO)		ENGINEERING
Mask		Type:
Gloves		Performance:

COMMENTS/REMARKS

………
………
………
………
………
………
………
………
………
………

INVESTIGATOR/FIELD WORKER

Name: …………………………………… Signed: …………………………………

Appendix 8

Permission letter from the study site

Sorbet
get that feeling

THE SORBET EXPERIENCE (PTY) LTD

1-8TH Avenue,
Corner Wessel Road,
RIVONIA 2128
Telephone: +27 11 202 7940
Facsimile: +27 11 234 6484
Email: info@sorbet.co.za

Website: www.sorbet.co.za

To Whom it May Concern. 5th April 2017

Subject: Permission to conduct the study titled "Assessment of Nail Technicians Exposure to Chemicals Found in Nail Salon Products in Gauteng, South Africa."

This serves to confirm that the researcher, Goitsemang Keretetse, from the University of Witwatersrand has explained her research study indicated above and expressed interest to recruit participants from our Franchises (Sorbet Salons) within the Gauteng area.

I, Rudi Rudolph therefore give permission to have the above mentioned study conducted at our Sorbet salons.

Yours Sincerely,

Mr Rudi Rudolph
COO for The Sorbet Group

Appendix 9

Consent form

INFORMED CONSENT

PARTICIPANT:

- I have read this consent form and have been given the chance to ask questions. I agree to participate in this research described above, titled: Occupational exposure to chemicals, and health outcomes, among nail technicians in Johannesburg, South Africa.
- I have also received, read and understood the Information Leaflet.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by the University of the Witwatersrand, or on their behalf.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) consent to participate in this study.

I agree to be audio-recorded ☐ Yes ☐ No ☐ NA

Printed Name **Signature / Mark or Thumbprint** **Date and Time**

FIELD WORKER:

I have given this research participant (or his/her legally authorized representative, if applicable) information about this study that I believe is accurate and complete. The participant has indicated that he or she understands the nature of the study and the risks and benefits of participating.

Printed Name **Signature** **Date and Time**

TRANSLATOR / OTHER PERSON EXPLAINING INFORMED CONSENT…………………**(DESIGNATION):**

Printed Name **Signature** **Date and Time**

WITNESS (If applicable)**:**

I observed the above participant (or his/her legally authorized representative, if applicable) sign this consent document

Printed Name **Signature** **Date and Time**

Appendix 10

Ethics Clearance Certificate

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

R14/49 Ms G Keretetse

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M171184

NAME: (Principal Investigator)	Ms G Keretetse
DEPARTMENT:	School of Public Health Medical School University
PROJECT TITLE:	Occupational exposure to chemicals and health outcomes amongst nail technicians in Johannesburg, South Africa
DATE CONSIDERED:	24/11/2017
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Professors DH Brouwer and G Nelson
APPROVED BY:	CBPenny Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	20/11/2018

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on 3rd floor, Phillip V Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.
I/We fully understand the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. When a funder requires annual re-certification, the application date will be one year after the date of the meeting when the study was initially reviewed. In this case, the study was initially reviewed in **November** and will therefore reports and re-certification will be due early in the month of **November** each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Keretetse
Principal Investigator Signature

11 January 2018
Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix 11

Turnitin Report

Turnitin report checked; similarity acceptable
G Nelson [signature]. 28/04/2023

Goitsemang Keretetse - PhD thesis_28 Apr 2023 Turnitin.docx

ORIGINALITY REPORT

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