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Pandemic products and volatile chemical emissions

Anne Steinemann[1,2] · Neda Nematollahi[1] · Behzad Rismanchi[1] · Nigel Goodman[3] · Spas D. Kolev[4]

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Abstract

The recent pandemic (COVID-19) has seen a sweeping and surging use of products intended to clean and disinfect, such as air sprays, hand sanitizers, and surface cleaners, many of which contain fragrance. However, exposure to fragranced cleaning products has been associated with adverse effects on human health. Products can emit a range of volatile chemicals, including some classified as hazardous, but relatively few ingredients are disclosed to the public. Thus, relatively little is known about the specific emissions from these products. This study investigates the volatile organic compounds (VOCs) emitted from "pandemic products" that are being used frequently and extensively in society. In addition, among these emissions, this study identifies potentially hazardous compounds, compares so-called green and regular versions of products, and examines whether ingredients are disclosed to the public. Using gas chromatography/mass spectrometry, 26 commonly used pandemic products, including 13 regular and 13 so-called green versions, were analyzed for their volatile emissions. Product types included hand sanitizers, air disinfectants, multipurpose cleaners, and handwashing soap. All products were fragranced. The analyses found the products collectively emitted 399 VOCs with 127 VOCs classified as potentially hazardous. All products emitted potentially hazardous compounds. Comparing regular products and green products, no significant difference was found in the emissions of the most prevalent compounds. Further, among the 399 compounds emitted, only 4% of all VOCs and 11% of potentially hazardous VOCs were disclosed on any product label or safety data sheet. This study reveals that pandemic products can generate volatile emissions that could pose risks to health, that could be unrecognized, and that could be reduced, such as by using fragrance-free versions of products.

Keywords Pandemic · Coronavirus · Fragranced consumer products · Volatile organic compounds · Emissions · Cleaning · Disinfectants · Hand sanitizers

Introduction

Cleaning and disinfection products are common in society, especially with increased frequency and extent of use during the coronavirus pandemic. The preponderant use of products—such as air fresheners and disinfectants, hand sanitizers and soaps, and multipurpose surface cleaners—appears to focus on the virus and not necessarily emissions, with the assumption that more use is better. Consequently, chemical exposures from products can be increasing across the population. However, and paradoxically, products intended to reduce risks to health may actually be posing risks to health, albeit in other ways. Important questions arise, such as the following: What is actually emitted from the products? Do any chemicals pose possible hazards? Are so-called green or natural products any different? Are product ingredients fully disclosed to the public?

This study investigates emissions from a range of cleaning and disinfectant products that have been commonly used during the pandemic, which this article terms "pandemic products." The study pursues four main objectives: (a) to analyze the volatile organic compounds (VOCs) emitted from a set of

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✉ Anne Steinemann
anne.steinemann@unimelb.edu.au

[1] Department of Infrastructure Engineering, Melbourne School of Engineering, The University of Melbourne, Parkville, Victoria 3010, Australia

[2] College of Science and Engineering, James Cook University, Townsville, Queensland 4814, Australia

[3] School of Property Construction and Project Management, RMIT University, Melbourne, VIC 3000, Australia

[4] School of Chemistry, The University of Melbourne, Parkville, Victoria 3010, Australia

typical fragranced pandemic products, (b) to identify the compounds classified as potentially hazardous, (c) to compare emissions between regular and so-called green versions of products, and (d) to assess whether compounds emitted are disclosed on product labels or safety data sheets. Results from this study can provide a scientific foundation to understand emissions from the use of pandemics products, and ways to reduce risks.

Cleaning and disinfection products have a history of associations with effects on health. Nazaroff and Weschler (2004) synthesize evidence of adverse health outcomes linked to chemical exposures from the use of cleaning products and air fresheners. In addition, use of fragranced cleaning products and air disinfectants has been associated with migraine headaches (e.g., Silva-Néto et al. 2014; Steinemann and Nematollahi 2020), asthma attacks and exacerbations (e.g., Zock et al. 2007; Weinberg et al. 2017; Steinemann and Goodman 2019), childhood wheeze (e.g., Parks et al., 2020; Sherriff et al. 2005), and additional health problems related to neurological, gastrointestinal, respiratory, dermatological, and immune systems (e.g., Steinemann 2019a).

In recent work, nationally representative population-based studies, across the United States, Australia, the United Kingdom, and Sweden, found that 32.2% of the general population on average (34.7%, 33.0%, 27.8%, 33.1%, respectively) report health problems when exposed to fragranced consumer products, including air fresheners, deodorizers, hand soaps, hand sanitizers, all-purpose cleaners, and disinfectants (Steinemann 2018a, b, 2017a, 2016).

Further, across these four countries, 17.4% of the general population, and 36.7% of asthmatics, report health problems when exposed to air fresheners and deodorizers. Also, 15.7% of the general population, and 32.9% of asthmatics, report health problems from being in a room after it has been cleaned by fragranced products (Steinemann 2019a, Steinemann and Goodman 2019).

In prior chemical analyses and comparisons of fragranced and fragrance-free cleaning products (Steinemann 2015; Nematollahi et al. 2019), all of the fragranced products emitted terpenes (e.g., limonene, alpha-pinene, beta-pinene), but none of the fragrance-free products emitted terpenes. Terpenes can act as both primary pollutants as well as react with ozone to generate a range of secondary pollutants, such as formaldehyde.

Methods

For this study, 26 common cleaning and disinfectant products, widely used and sold in two countries (the United States and Australia), were randomly selected and analyzed for their emissions. Product types were hand sanitizers, air disinfectants, multipurpose cleaners and disinfectants, and handwashing soap; each of the products was fragranced (see Table 1).

The products selected include both "green" and "regular" versions. Herein, the term "green" refers to products with the claim of being "green" or related terms, such as "natural" or "organic." The term "regular" refers to products other than those in the "green" category.

Criteria for selection as a "pandemic product" were (i) a government issued public health recommendation for a product type to be used more frequently and extensively for purposes against the coronavirus, (ii) a government issued approval for a specific product to be used for purposes against the coronavirus, or (iii) both.

To determine the volatile ingredients, headspace gas chromatography/mass spectrometry (GC/MS) was used to analyze the VOCs emitted from the products. The chromatogram for each product was scanned to identify the highest concentration VOCs (top 20 peaks). Compound identification was based on the mass spectral library of the National Institute of Standards and Technology NIST Version 2.0 (see Nematollahi et al. 2018; Steinemann et al. 2011 for additional details on the analytic methods). Chromatographic data for each product, as reported in supplementary tables of Nematollahi et al. (2019) and Steinemann (2015), were reanalyzed for the purposes of this study, including new analyses of VOC prevalences, hazardous compound classifications, comparisons of regular and green products, ingredient disclosures, and product claims related to the pandemic.

Potentially hazardous VOCs were identified according to classifications of (i) hazardous air pollutants (HAPs), United States Environmental Protection Agency (EPA 2017), including carcinogenic HAPs (EPA 2018), (ii) Hazardous Chemical Information System (HCIS), Safe Work Australia (SWA 2020), and (iii) asthmagens, Association of Occupational and Environmental Clinics (AOEC 2020). This analysis was performed to identify ingredients that are classified as potentially hazardous under one or more of these criteria. However, this analysis does not imply an evaluation of product safety or risks.

Table 1 Types of tested products

	Hand sanitizer	Air disinfectant	Multipurpose cleaners and disinfectants	Handwashing soap	Total
Regular	1	3	5	4	13
Green	1	2	6	4	13
Total	2	5	11	8	26

It also does not imply that these VOCs are the only potentially hazardous compounds emitted or generated from the products.

Results

VOCs emitted and most prevalent VOCs

A summary of VOCs emitted across the 26 cleaning products, both regular and green, is provided in Table 2. In this paper, the term "VOC occurrences" refers to the number of individual VOCs emitted from the products, such that each VOC occurrence represents a single volatile ingredient in a single product. The term "VOC identities" refers to the number of distinctly named VOCs emitted from the products, such that each VOC identity represents a compound, according to name and CAS number, that occurs in one or more of the products.

Across the 26 cleaning products, 399 VOCs were emitted (occurrences), representing 172 VOCs identities. The most prevalent VOCs (in at least 40% of all products) were limonene, ethanol, alpha-pinene, beta-pinene, and acetaldehyde (Table 3). In both "regular" and "green" products, the most prevalent VOC was limonene. Data on emissions from each specific product, as well as the most prevalent VOCs across the products, are provided in Supplementary Tables 1 and 2.

Potentially hazardous emissions

For the 399 VOCs (occurrences) emitted collectively from the 26 products, 127 VOCs are classified as potentially hazardous, representing approximately 30% of all VOC ingredients. All products emitted between 1 and 4 VOCs classified as potentially hazardous.

For the 172 VOCs (identities) emitted across the 26 products, 46 VOCs are classified as potentially hazardous. The most prevalent potentially hazardous VOCs (in at least 25% of all cleaning products) were limonene, ethanol, acetaldehyde, 3-carene, and methanol (Table 4).

Comparison of VOCs emitted from regular and green products

Among the most prevalent VOCs, no significant difference was found in the VOC identities and occurrences between the regular and green products ($p = 0.11$, t test). In addition, among the most prevalent potentially hazardous VOCs, no significant difference was found in VOC identities and occurrences between regular and green products ($p = 0.17$, t test). This comparison followed the convention of previously published work (e.g., Steinemann 2015, Nematollahi et al. 2019) that analyzed and compared regular and green products.

Comparison of VOCs emitted and ingredients disclosed

Among the 399 VOCs emitted from the products, only 16 were listed on any product label or safety data sheet. In addition, among the 127 VOCs classified as potentially hazardous emitted from the products, only 14 were listed on any product label or safety data sheet (Table 2). Thus, only 4% of all VOCs, and 11% of the potentially hazardous VOCs, were disclosed to the public on product labels or safety data sheets.

Discussion

This study found that fragranced pandemic products of all types, including both regular and green versions, emit numerous volatile chemicals, some of which are classified as hazardous, and few of which are disclosed to the public. Thus, chemical emissions and associated risks may be largely unrecognized. Results are especially concerning given that chemical exposures may be involuntary, and affect vulnerable populations such as children, the elderly, and individuals in institutions and care facilities.

Our findings are consistent with prior studies of fragranced cleaning products and air fresheners (Steinemann 2015, 2017b, 2019a, b; Steinemann et al. 2011; Nematollahi et al. 2019, 2018; Uhde and Schulz 2015) as follows. First, terpenes

Table 2 VOCs emitted from products*

Type	Number of products	Emitted		Listed (on product label or safety data sheet)	
		All VOCs	Potentially hazardous VOCs	All VOCs	Potentially Hazardous VOCs
Regular	13	211 occurrences 122 identities	61 occurrences 35 identities	4 occurrences 3 identities	4 occurrences 3 identities
Green	13	188 occurrences 96 identities	58 occurrences 24 identities	7 occurrences 5 identities	5 occurrences 3 identities
Total	26	399 occurrences 172 identities	127 occurrences 46 identities	16 occurrences 7 identities	14 occurrences 5 identities

*"VOC occurrences" refers to the number of individual VOCs emitted from the products

"VOC identities" refers to the number of distinctly named VOCs emitted from one or more of the products

Table 3 Most prevalent VOCs emitted from products

Compound	CAS #	Prevalence (# of products)		
		Total ($n = 26$)	Regular ($n = 13$)	Green ($n = 13$)
All products ($n = 26$)				
Limonene*	138-86-3	21	10	11
Ethanol*	64-17-5	17	7	10
alpha-Pinene	80-56-8	13	7	6
beta-Pinene	127-91-3	12	8	4
Acetaldehyde*	75-07-0	11	4	7
Eucalyptol	470-82-6	11	4	7
gamma-Terpinene	99-85-4	11	5	6
beta-Myrcene	123-35-3	10	1	9
beta-trans-Ocimene	3779-61-1	10	3	7
Camphene	79-92-5	10	5	5
3-Carene*	13,466-78-9	8	4	4
beta-Phellandrene	555-10-2	8	5	3
Linalool	78-70-6	8	4	4
alpha-Phellandrene	99-83-2	7	3	4
Methanol*	67-56-1	7	3	4
Regular products ($n = 13$)				
Limonene*	138-86-3		10	
beta-Pinene	127-91-3		8	
Ethanol*	64-17-5		7	
alpha-Pinene	80-56-8		7	
gamma-Terpinene	99-85-4		5	
Camphene	79-92-5		5	
beta-Phellandrene	555-10-2		5	
Acetaldehyde*	75-07-0		4	
Eucalyptol	470-82-6		4	
3-Carene*	13,466-78-9		4	
Linalool	78-70-6		4	
6-Methyl-5-hepten-2-one	110-93-0		4	
o-Cymene	527-84-4		4	
Butane*	106-97-8		4	
alpha-Terpinene	99-86-5		4	
Green products ($n = 13$)				
Limonene*	138-86-3			11
Ethanol*	64-17-5			10
beta-Myrcene	123-35-3			9
Acetaldehyde*	75-07-0			7
Eucalyptol	470-82-6			7
beta-trans-Ocimene	3779-61-1			7
alpha-Pinene	80-56-8			6
gamma-Terpinene	99-85-4			6
Camphene	79-92-5			5
beta-Pinene	127-91-3			4
3-Carene*	13,466-78-9			4
Linalool	78-70-6			4
alpha-Phellandrene	99-83-2			4
Methanol*	67-56-1			4
Acetone*	67-64-1			4

*Classified as potentially hazardous

(e.g., limonene) were the most commonly emitted ingredients. Second, all types of products, even green versions, emitted potentially hazardous VOCs. Third, no significant difference was found in emissions between regular and green products. Fourth, across the studies, fewer than 10% of volatile ingredients were disclosed to the public on product labels, safety data sheets, websites, or elsewhere.

However, this lack of full ingredient disclosure is permissible. Cleaning products are not required to disclose all of their specific ingredients. Further, a "fragrance" in a product is also exempted from full ingredient disclosure, even though a fragrance is typically a complex mixture of dozens of chemicals. Although products regulated as drugs or cosmetics need to list

Table 4 Potentially hazardous VOCs emitted from the products

Compound	CAS #	Prevalence (# of products)			HAPs	SWA	Asthmagens
		Total ($n = 26$)	Regular ($n = 13$)	Green ($n = 13$)			
Limonene	138-86-3	21	10	11		✓	
Ethanol	64-17-5	17	7	10		✓	
Acetaldehyde**	75-07-0	11	4	7	✓	✓	
3-Carene	13,466-78-9	8	4	4			✓
Methanol	67-56-1	7	3	4	✓	✓	
Acetone	67-64-1	5	1	4		✓	
Butane	106-97-8	5	4	1		✓	
1-Octanol	111-87-5	3	0	3		✓	
Cyclohexane	110-82-7	3	2	1		✓	
Ethyl acetate	141-78-6	3	2	1		✓	
Pentane	109-66-0	3	1	2		✓	
(E)-citral	141-27-5	2	1	1		✓	
2-Methyl-2-propanol	75-65-0	2	2	0		✓	
Acetaldehyde diethyl acetal	105-57-7	2	1	1		✓	
beta-Citral	106-26-3	2	1	1		✓	
Butanone	78-93-3	2	1	1		✓	
Isopropyl alcohol	67-63-0	2	1	1		✓	
1,1-Dichloroethylene	75-35-4	1	1	0	✓	✓	
2,4-Dimethylpentane	108-08-7	1	1	0		✓	
2-Chlorotoluene	95-49-8	1	0	1		✓	
2-Methyl-1-propene	115-11-7	1	1	0		✓	
3-Methylhexane	589-34-4	1	0	1		✓	
5-Methylheptan-3-one	541-85-5	1	1	0		✓	
Allyl alcohol	107-18-6	1	1	0		✓	
Benzaldehyde	100-52-7	1	0	1		✓	
Benzyl alcohol	100-51-6	1	0	1		✓	
Butyraldehyde	123-72-8	1	0	1		✓	
Carbon tetrachloride**	56-23-5	1	1	0	✓	✓	
Chloroform**	67-66-3	1	1	0	✓	✓	
Citral	5392-40-5	1	0	1		✓	
E-2-butene	624-64-6	1	1	0		✓	
Ethyl formate	109-94-4	1	0	1		✓	
Heptan-4-one	123-19-3	1	1	0		✓	
Heptane	142-82-5	1	1	0		✓	
Hexane	110-54-3	1	1	0	✓	✓	
Isoamyl acetate	123-92-2	1	1	0		✓	
Isobutane	75-28-5	1	1	0		✓	
Methyl acetate	79-20-9	1	0	1		✓	
Methyl isobutyl ketone	108-10-1	1	0	1	✓	✓	
N,N-dimethylacetamide	127-19-5	1	1	0		✓	
Octane	111-65-9	1	1	0		✓	
Propane	74-98-6	1	1	0		✓	
Propylene glycol butyl ether	5131-66-8	1	1	0		✓	
Styrene**	100-42-5	1	1	0	✓	✓	✓
Tetracarbonylnickel	13,463-39-3	1	1	0		✓	✓
Toluene	108-88-3	1	1	0	✓	✓	

HAPs, Hazardous Air Pollutants (HAPs), United States Environmental Protection Agency (EPA 2017),

**Classified as possibly carcinogenic (2B) (EPA 2018)

SWA, Hazardous Chemical Information System (HCIS), Safe Work Australia (SWA 2020)

Asthmagens, Association of Occupational and Environmental Clinics (AOEC 2020)

ingredients, the general term "fragrance" may be listed, instead of specific compounds (see Steinemann 2009; Lunny et al. 2017).

Terpenes are characteristic of fragranced consumer products. In comparisons of fragranced and fragrance-free versions of products, terpenes are the most prevalent compounds in fragranced products, but they are absent in fragrance-free products (Steinemann 2015; Nematollahi et al. 2019). Terpenes are not only primary pollutants, but they also generate a range of secondary pollutants. Thus, choosing products without fragrance could reduce exposures to terpenes and other fragrance compounds, which can include potentially hazardous air pollutants

and allergens. To note, unscented products are not necessarily fragrance-free, as they can contain fragrance compounds to cover the scent (Steinemann 2019a).

Limitations of the study include the following. The GC/MS headspace analysis identified volatile ingredients that are directly emitted from the product without interactions with ambient air. Thus, the analysis would not have captured a range of secondary pollutants, such as through terpene-ozone interactions, that could contribute to product risks. The study also focused on volatile organic compounds, and products can contain other classes of chemicals, such as semivolatile organic compounds. The GC/MS analysis examined emissions from a single product, whereas emissions from multiple products used together could generate chemical reactions that pose additional risks. Finally, while the study identified specific compounds as well as broader public health issues, the analysis was not intended as a quantification of risks from product use.

Results from the study lead to a question: Are there alternative products that could provide equivalent functionality against the virus but without emissions that may be problematic for health? Given that fragranced cleaning products have been associated with reports of health problems, and that fragrance in product is added for aesthetics, fragrance-free products could offer reasonable alternatives.

Conclusions

This study provides findings on the VOCs emitted by 26 products frequently and extensively used during the pandemic. The analysis found 399 VOC ingredients, with 127 VOCs classified as potentially hazardous, emitted from the products. Limonene was the most commonly emitted compound, found in 80% of products. Emissions of the most prevalent potentially hazardous VOCs from regular and green fragranced products were not significantly different. Only 4% of all VOCs and 11% of potentially hazardous VOCs were listed on any product label. Results of this study can help to improve awareness about emissions from pandemic products, and provide a foundation for understanding and reducing risks of product use.

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