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Emissions from dryer vents during use of fragranced and fragrance-free laundry products

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Abstract

Fragranced laundry products emit a range of volatile organic compounds, including hazardous air pollutants. Exposure to fragranced emissions from laundry products has been associated with adverse health effects such as asthma attacks and migraine headaches. Little is known about volatile emissions from clothes dryer vents and the effectiveness of strategies to reduce concentrations and risks. This study investigates volatile emissions from six residential dryer vents, with a focus on D-limonene. It analyses and compares concentrations of D-limonene during use of fragranced and fragrance-free laundry products, as well as changes in switching from fragranced to fragrance-free products. In households using fragranced laundry detergent, the highest concentration of D-limonene from a dryer vent was 118 μg/m^3 (mean 33.34 μg/m^3). By contrast, in households using only fragrance-free detergent, the highest concentration of D-limonene from a dryer vent was 0.26 μg/m^3 (mean 0.25 μg/m^3). After households using fragranced detergent switched to using fragrance-free detergent, the concentrations of D-limonene in dryer vent emissions were reduced by up to 99.7% (mean 79.1%). This simple strategy of switching to fragrance-free products significantly and almost completely eliminated D-limonene emissions. Results from this study demonstrate that changing from fragranced to fragrance-free products can be a straightforward and effective approach to reduce ambient air pollution and potential health risks.

Keywords Dryer vent · Fragrance · Fragrance-free · Detergent · Laundry · Emissions · Volatile organic compounds · VOC · Air quality

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Introduction

Volatile organic compounds (VOCs) are a category of air pollutants that typically occur at much higher concentrations indoors (Bari et al. 2015; Cheng et al. 2016; Goodman et al. 2017). Primary sources of indoor VOCs are fragranced consumer products such as air fresheners, cleaning products, and laundry supplies (Steinemann et al. 2013; Steinemann 2015). Volatile chemical emissions from products used indoors can also migrate outdoors and affect outdoor air quality (Steinemann et al. 2013; McDonald et al. 2018; Lewis 2018).

Fragranced laundry products emit a range of VOCs such as acetaldehyde, acetone, ethanol, α-pinene, linalool, and D-limonene (Steinemann et al. 2013). Some of these VOCs are classified as potentially hazardous and can have adverse effects on human health and the environment (Mendell 2007; Rumchev et al. 2004; Spengler et al. 2000). In particular, exposure to D-limonene has been associated with adverse health effects such as skin and eye irritation (NIH 2018) and breathing difficulties such as wheezing or coughing (NICNAS 2018). Furthermore, terpenes such as D-limonene can react with ozone to generate hazardous air pollutants such as formaldehyde, acetaldehyde, and ultrafine particles (Nazaroff and Weschler 2004).

Exposure to fragranced emissions from dryer vents has been associated with adverse health effects in the general population and in vulnerable sub-populations. Recent national studies in the USA, Australia, the UK, and Sweden (Steinemann 2016, 2017, 2018, 2018b) found that 12.5%, 6.1%, 6.0%, and 5.6% (respectively) of adults reported adverse health effects such as asthma attacks and migraine headaches from the fragrance of laundry products coming from a dryer vent. In addition, national studies of asthmatics in the USA and Australia (Steinemann 2018c; Steinemann et al. 2018) found that 28.9% and 12.1% (respectively) of adults with diagnosed asthma or an asthma-like condition reported adverse health effects from the fragrance of laundry products coming from a dryer vent. An earlier study in the USA (Caress and Steinemann 2009) found that 10.9% of the general population, and 21.2% of asthmatics, reported adverse effects from fragranced laundry products vented outdoors.

Prior work (Steinemann et al. 2013) analysed VOC emissions from residential dryer vents during the use of fragranced laundry products such as detergents and dryer sheets. The study found more than 25 VOCs emitted from the dryer vents, including nine compounds classified as toxic or hazardous, with highest concentrations of acetaldehyde, acetone, methanol, ethanol, and limonene.

Chemical analyses of fragranced laundry products found that D-limonene was the most prevalent VOC ingredient (Steinemann 2015). By contrast, D-limonene was not found in fragrance-free laundry products (Steinemann 2015). Fragrance-free laundry products generally do not contain terpenes (Steinemann 2015), and thus may provide an option to reduce emissions of VOCs including potentially hazardous air pollutants.

The purpose of this study is to analyse, quantify, and compare emissions from use of fragranced and fragrance-free laundry products. In addition, it investigates potential reductions in D-limonene by switching from fragranced to fragrance-free products. Findings will address an understudied yet pervasive environmental and health problem, namely exposure and emissions associated with venting laundry products. It also explores a practical and cost-effective approach to improve indoor and outdoor air quality and reduce pollutant exposures.

Methods

Experimental protocol

The study was conducted over 1 month at six households located within 75 km of Melbourne, Australia. To be eligible for the study, households needed to have an internally vented electrically heated clothes dryer, and be able to wash and dry at least one load of clothing per week. Four households had been using fragranced laundry products ("fragranced households"). Two households had been using exclusively fragrance-free laundry products ("fragrance-free households").

For the study, the research team selected a leading brand of fragranced laundry detergent and corresponding fragrance-free laundry detergent, purchased the products at local stores, and provided them unopened to households. All households used the same fragranced or fragrance-free laundry detergents throughout the study. The research team also purchased and provided sets of identical new towels to all households. A detailed protocol describing sampling and household activities is provided in Table 1. This study received ethics approval from The University of Melbourne (Application number: 1749053.1).

As preparation, the four fragranced households and two fragrance-free households used the designated fragranced laundry detergent and fragrance-free laundry detergent, respectively, for at least two loads of washing and drying. To commence the study, samples were taken at the four fragranced households. Then, for a period of 1 month, the fragranced households switched from the fragranced laundry detergent to the fragrance-free laundry detergent. The fragrance-free households continued to use the fragrance-free detergent. After 1 month, samples were taken at the four (formerly) fragranced and two fragrance-free households. (See Table 1 for details.)

Before each round of sampling, the washer and dryer interiors were wiped down with clean paper towels and water, washers were operated empty in drum clean mode, dryers were operated empty on the highest temperature for 10 min, and the dryer lint filter was removed, cleaned, and reinstalled. Machines and detergents were used according to the manufacturer's instructions. For each round of sampling, at each household, a set of four new cotton towels was washed and dried according to the protocol described in Table 1.

Air samples were collected from (a) the laundry room background air before any washing or drying activities, (b) the clothes dryer vent after washing towels without any products (i.e. water only), and (c) the clothes dryer vent after washing the same towels with either fragranced or fragrance-free laundry detergent. A total of six samples were collected from each fragranced household (three before and three after switching products), and three samples collected from each fragrance-free household.

Indoor air samples were collected following USEPA compendium methods TO 17 (US EPA 1999). For VOCs (i.e. D-limonene), a single multi-adsorbent tube (Markes Carbograph 1TD/Carbopack X) was connected to an SKC sampling pump (AirChek 220-5000TC) at a flow rate of approximately 150 mL per minute for 1 h (9 L). The flow rate of the pump was calibrated three times (beginning, middle, and end) during sample collection using a Defender 510 Low Flow Calibrator (Mesa Labs). Temperature, relative humidity, and barometric pressure were measured using a portable indoor air quality

Table 1 Sampling protocol for laundry cycles and air sampling in fragranced and fragrance-free households

Time period	Activity	
	Fragranced households	Fragrance-free households
Week 0	As preparation, the four fragranced households used the designated fragranced laundry detergent for 1 week to wash and dry at least two loads of laundry.	As preparation, the two fragrance-free households used the designated fragranced-free laundry detergent for 1 week to wash and dry at least two loads of laundry.
Week 1	Fragranced detergent—sampling At the beginning of Week 1, the first round of sampling for the fragranced households commenced. Sample (a) Laundry room air. Air samples were taken in the room before any washing or drying activities, for a period of 1 h. Sample (b) No products. Using only new towels in the wash and dry cycle, samples were taken at the dryer vent outlet, immediately after the dryer started, for period of 1 h. Sample (c) Fragranced liquid laundry detergent. One capful of detergent was used with the towels in the washing machine. Samples were taken at the dryer vent outlet, immediately after the dryer started, for period of 1 h.	Fragrance-free detergent—no sampling
Weeks 1–4	Switch from fragranced to fragrance-free detergent At the beginning of Week 1, after the sampling, the four fragranced households switched to the designated fragrance-free detergent. Households washed and dried at least one load per week, and did not use fragranced laundry products in either machine. This activity continued for 4 weeks.	Fragrance-free detergent At the beginning of Week 1, the two fragrance-free households continued to use the designated fragrance-free laundry detergent. Households washed and dried at least one load per week, and did not use any fragranced laundry products in either machine. This activity continued for 4 weeks.
Week 4	Fragrance-free detergent—sampling At the end of Week 4, the second round of sampling for the fragranced (now fragrance-free) households commenced. Sample (d) Laundry room air. Air samples were taken in the room before any washing or drying activities, for a period of 1 h. Sample (e) No products. Using only new towels in the wash and dry cycle, samples were taken at the dryer vent outlet, immediately after the dryer started, for period of 1 h. Sample (f) Fragrance-free liquid laundry detergent. One capful of detergent was used with the towels in the washing machine. Samples were taken at the dryer vent outlet, immediately after the dryer started, for period of 1 h.	Fragrance-free detergent—sampling At the end of Week 4, the first round of sampling for the fragrance-free households commenced. Sample (g) Laundry room air. Air samples were taken in the room before any washing or drying activities, for a period of 1 h. Sample (h) No products. Using only new towels in the wash and dry cycle, samples were taken at the dryer vent outlet, immediately after the dryer started, for period of 1 h. Sample (i) Fragrance-free liquid laundry detergent. One capful of detergent was used with the towels in the washing machine. Samples were taken at the dryer vent outlet, immediately after the dryer started, for period of 1 h.

monitor (TSI Q Trak 7575). The background air samples were collected in the centre of each laundry room with all machines turned off. During the clothes dryer experiments, a clean 100-mm aluminium duct (1.5–2.5 m long) was connected to the exit of the clothes dryer to allow sample collection. Samples were collected at a distance of approximately 200 mm from the outlet of the aluminium duct. In all cases, the air sampling point was approximately 1.2 m above floor level. This height was chosen as it provided a secure location for the aluminium ducting, sampling pump, and indoor air quality monitor.

Analytical methods

Analysis of VOCs used a Markes Series 2 Ultra Autosampler, a Markes Series 2 Unity Thermal Desorption (TD) unit, an Agilent 7890A gas chromatograph (GC), and an Agilent 5975c Inert Mass Selective Detector (MSD) with Triple-Axis Detector mass spectrometer (MS) in accordance with US EPA method TO-17 (US EPA 1999). An Agilent (DB-5MS) capillary column (60 m × 0.32 mm × 1 μm) was used for the separation. A certified D-limonene standard (AccuStandard, ALR-022N, lot number: 17626) and a quality control (QC) standard (Supelco, certified reference material (CRM) 40448, lot number: XA22031V) were used for the calibration and for QC. Only samples with concentrations greater than the method detection limit (MDL) of the analytical instrument were reported. All VOC data were reported in units of μg/m^3 and corrected for temperature and pressure at 101.3 kPa and 0 °C.

Both fragranced and fragrance-free laundry detergents were analysed for their VOC ingredients and emissions using gas chromatography/mass spectrometry (GC/MS) headspace analysis. Details of the headspace analysis and GC/MS specifications are provided in Nematollahi et al. 2018.

The study focused on D-limonene because it is (a) a prevalent and dominant VOC in fragranced laundry products as well as other fragranced consumer products, (b) a suitable marker as it is generally found in fragranced laundry products but not in fragrance-free laundry products, (c) associated with

Table 2 Concentration of d-limonene (μg/m^3) in fragranced households, before and after switch from fragranced to fragrance-free laundry product, and in fragrance-freehouseholds[i, ii]

Household Number and Type	Laundry Room Background Air				Dryer Vent Samples, No Products				Dryer Vent Samples, With Products			
	Before switch from F to FF product (μg/m^3) *sample (a)*	After switch from F to FF product (μg/m^3) *sample (d)*	Reduction in d-limonene (%) *(a - d)/(a)*	FF product (μg/m^3) *sample (g)*	Before switch from F to FF product (μg/m^3) *sample (b)*	After switch from F to FF product (μg/m^3) *sample (e)*	Reduction in d-limonene (%) *(b - e)/(b)*	FF product (μg/m^3) *sample (h)*	Before switch from F to FF product (μg/m^3) *sample (c)*	After switch from F to FF product (μg/m^3) *sample (f)*	Reduction in d-limonene (%) *(c - f)/(f)*	FF product (μg/m^3) *sample (i)*
#1(F)	0.70	0.59	15.7	-	1.13	1.02	9.7	-	2.35	1.50	36.2	-
#2 (F)	0.23	0.12	47.8	-	1.24	0.13	89.5	-	10.52	0.13	98.8	-
#3 (F)	0.47	0.25	46.8	-	0.37	0.63	(-70.3)	-	2.51	0.46	81.7	-
#4 (F)	1.28	0.35	72.7	-	0.61	0.26	57.4	-	118	0.36	99.7	-
#5 (FF)	-	-	-	0.24	-	-	-	0.40	-	-	-	0.26
#6 (FF)	-	-	-	0.35	-	-	-	0.49	-	-	-	0.24

i: sample letters in parentheses refer to protocol in Table 1

ii: F= fragranced; FF = fragrance-free

a range of adverse human health and environmental effects, and classified as a potentially hazardous compound (SWA 2018), and (d) a terpene that readily reacts with ozone to generate a range of hazardous secondary air pollutants.

Results

Concentrations at fragranced and fragrance-free households

Concentrations of D-limonene at each phase of sampling and at each household are provided in Table 2.

At fragranced households 1–4, before switching to fragrance-free products, the concentration of D-limonene in (a) the background laundry room air ranged between 0.23–1.28 μg/m^3 (mean 0.67 μg/m^3), (b) the clothes dryer vent after washing new towels without any products ranged between 0.37–1.24 μg/m^3 (mean 0.84 μg/m^3), and (c) the clothes dryer vent after washing the same towels with fragranced laundry products ranged between 2.35–118 μg/m^3 (mean 33.34 μg/m^3).

At these same fragranced households 1–4, after switching to fragrance-free products, the concentration of D-limonene in (a) the background laundry room air ranged between 0.12–0.59 μg/m^3 (mean 0.33 μg/m^3), (b) the clothes dryer vent after washing new towels without any products ranged between 0.26–1.02 μg/m^3 (mean 0.51 μg/m^3), and (c) the clothes dryer vent after washing the same towels with fragrance-free products ranged between 0.13–1.50 μg/m^3 (mean 0.61 μg/m^3).

At the fragrance-free households 5–6, the concentration of D-limonene in (a) the background laundry room air ranged between 0.24–0.35 μg/m^3 (mean 0.29 μg/m^3), (b) the clothes dryer vent after washing new towels without any products ranged between 0.40–0.49 μg/m^3 (mean 0.44 μg/m^3), and (c) the clothes dryer vent after washing the same towels with fragrance-free products ranged between 0.24–0.26 μg/m^3 (mean 0.25 μg/m^3).

Concentration reduction after switching from fragranced to fragrance-free laundry products

After switching from fragranced laundry products to fragrance-free laundry products, at (formerly) fragranced households 1–4, the concentrations of D-limonene decreased in all samples of the laundry room air and emissions with use of products (Table 1).

In background laundry room air, the D-limonene concentration decreased by up to 72.7% (range: 15.7–72.7%, mean 45.8%). When drying towels washed without any detergent, the D-limonene concentration decreased by up to 89.5% (range: 9.7–89.5%, mean 21.6%). When drying towels washed with detergent (now fragrance-free products after switching from fragranced products), the D-limonene concentration decreased by up to 99.7% (range: 36.2–99.7%, mean 79.1%). Further, the D-limonene concentrations in samples from the formerly fragranced households 1–4 were approaching the lower levels of samples from fragrance-free households 5–6.

The GC/MS headspace analysis of the laundry products used in this study is shown in Table 3. In the fragranced laundry

Table 3 GC/MS headspace analysis of VOCs emitted from the fragranced laundry detergent and the fragrance-free laundry detergent used in this study, listed according to retention time

Compound	CAS #	Fragranced detergent	Fragrance-free detergent
Acetaldehyde*	75-07-0	✓	✓
Ethanol*	64-17-5	✓	
Acetone*	67-64-1	✓	✓
2-methyl-Pentane*	107-83-5	✓	
2-methyl-2-Propanol	75-65-0		✓
2-Propen-1-ol*	107-18-6	✓	
2-methyl-Hexane*	591-76-4	✓	
2,3-dimethyl-Pentane*	565-59-3	✓	
3-methyl-Hexane*	589-34-4	✓	
1,3-dimethyl-Cyclopentane	2453-00-1	✓	
Ethylbenzene*	100-41-4		✓
Heptane*	142-82-5	✓	
methyl-Cyclohexane*	108-87-2	✓	
2,3,4-trimethyl-Hexane	921-47-1	✓	
(E)-3-Hexen-1-ol	928-97-2	✓	
1-Hexanol*	111-27-3	✓	
α-Pinene	80-56-8	✓	
2-methyl-ethyl ester Pentanoic acid	39255-32-8	✓	
Sabinene	3387-41-5	✓	
3-Carene	13466-78-9	✓	
β-Myrcene	123-35-3	✓	
β-Ocimene	3779-61-1	✓	
4-Hexen-1-ol, acetate	72237-36-6	✓	
Acetic acid, hexyl ester	142-92-7	✓	
Octanal	124-13-0	✓	
D-Limonene*	5989-27-5	✓	
β-Phellandrene	555-10-2	✓	
2,6-dimethy-l-5-Heptenal	106-72-9	✓	
2,6-dimethyl-7-Octen-2-ol	18479-58-8	✓	
1,3,4-Trimethyl-3-cyclohexenyl-1-carboxaldehyde	40702-26-9	✓	
Linalool*	78-70-6	✓	
3-methyl-5-propyl-Nonane	31081-18-2		✓
(E)- 7-Tetradecene	41446-63-3		✓
Cyclododecane	294-62-2		✓
Benzyl acetone	2550-26-7	✓	
4-tert-Butylcyclohexyl acetate	104-05-2	✓	
α-Terpinyl acetate	98-55-5	✓	
2-Carene	554-61-0	✓	
Lilial*	80-54-6	✓	

* Classified as hazardous under Safe Work Australia, Hazardous Chemical Information System (SWA 2018)

product, 34 VOCs were detected, and in the fragrance-free laundry product, 7 VOCs were detected. As in previous studies (e.g. Steinemann 2015), terpenes such as D-limonene were found in the fragranced product but not found in the fragrance-free product.

Discussion

This study investigated the concentrations of D-limonene emitted from residential dryer vents during use of fragranced and fragrance-free laundry products, and then changes in concentrations after switching from fragranced to fragrance-free laundry products. After 4 weeks of using fragrance-free products, D-limonene concentrations were reduced by up to 99.7% in dryer vent emissions and by up to 72.7% in laundry room air. What is notable is that this reduction was achieved after a relatively short period of time (1 month); it was straightforward to implement and incurred no extra costs or apparent inconvenience on participants.

A strength of this study is the participation of households that use the products in everyday life, demonstrating the practicably achievable reductions in concentrations by switching products. Yet this strength has a corresponding limitation in that the households continued to wash clothing as normal, which may have subjected the machines to track-in fragrances from clothing during the 4-week period of using fragrance-free products. In addition, while reductions in D-limonene approached levels of fragrance-free households, it is conceivable that using fragrance-free products for a longer period of time would result in even further reductions, as the residual fragrance chemicals are removed from the machines and clothing. For instance, residual fragrance chemicals in machines could help explain the anomalous value for household #3 for sample (e) showing an increase in D-limonene. The variety of D-limonene concentrations among households could also be attributed to differences in laundry equipment, laundry rooms, clothing, and factors such as water quality and ambient air quality. Due to the relatively small sample size, and the differences between the study sites, a statistical analysis of significance was not sufficiently powerful. Finally, while this study focused on D-limonene, given the results of the headspace analysis of both products, it is likely that other VOCs, particularly terpenes and resulting secondary pollutants, could also be reduced.

Conclusions

This study demonstrated the improvements to air quality after switching from fragranced to fragrance-free products. It found that, by a change to fragrance-free laundry products, concentrations of D-limonene can be almost completely eliminated from the dryer vent emissions. This strategy may also reduce the formation and concentrations of secondary pollutants such as formaldehyde, acetaldehyde, and ultrafine particles. Findings from this study can provide an important foundation for future research, and for demonstrating cost-effective strategies to reduce VOC emissions and personal exposures.

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