1. Introduction

- It has been reported that environmental tobacco smoke (i.e., exhaled tobacco smoke + smoke from a smoldering tobacco product) may become sorbed onto surfaces in areas where people have smoked conventional cigarettes, and subsequently re-emitted over time [1].
- It has been suggested that nicotine in smoke deposits almost entirely on indoor surfaces, where it can be released again to the gas phase or react with ozone, ambient nitric acid and other atmospheric oxidants producing secondary chemicals, such as tobacco-specific nitrosamines (TSNAs) [2].
- This scenario has been termed “third-hand smoke”. Some researchers have suggested that this may present a potential health hazard to bystanders [1,2].
- Electronic cigarettes (e-cigarettes) represent a rapidly-emerging product category that holds promise as a conventional tobacco cigarette alternative.
- As e-cigarettes do not contain tobacco and there is no side-stream aerosol generated, the only source of potential bystander exposure would be to nicotine in the exhaled aerosol.
- Although numerous studies have demonstrated that exhaled e-cigarette aerosols contain negligible amounts of nicotine [reviewed in [3]], there is currently a debate as to whether e-cigarette use results in the deposition of nicotine on surfaces resulting in a risk of so-called “third-hand exposure”.
- As there have been some publications on this topic, we wished to (i) explore whether nicotine is deposited on the walls and desk in a small office following use of a typical closed and open system e-cigarette by experienced users and (ii) assess the subsequent potential formation of TSNAs.

2. Setting, Sampling and Analysis

Products
Two experiments were conducted using two different commercial products: (i) Blu® PLUS closed system e-cigarette (containing replaceable cartridges by manufacturer) and (ii) Blu™ PRO open system (retailed by the consumer) both containing 1.8% nicotine classic tobacco flavour e-liquid.

Setting
Both experiments were conducted in a UK office of dimensions 4.20 x 2.95 x 3.05 m³ (surface, 12.4 m²; volume, 37.8 m³). The office was under natural ventilation conditions (i.e. no air conditioning and all windows open) and was kept closed during the study; the average measured ventilation rate was 0.7 l/min changes per hour. The temperature and relative humidity in the office over the course of the studies were in the range 17–24 °C and 28–45%, respectively.

E-cigarette aerosol was generated by three experienced e-cigarette users who used the products ad libitum over the course of 135 min in the office (Figure 1).

Surface Sample Collection
Surface wipe samples were collected before e-cigarette use was permitted (control period) from the walls and desk flat surface close to the e-cigarette users in the office and then 40 min and 24 h after e-cigarette use ceased. Before each experiment, all surfaces were rigorously cleaned with methanol.

Wipe samples were taken as described by Cuesta et al. (2013) [4] using KimWipes. Metal templates with a 30 x 30 cm² opening area were attached to each surface. The area inside the template was wiped in a zig-zag pattern from left to right, right to left and then top to bottom, bottom to top twice. Two replicate samples were taken at each time point from each surface. After sampling, the wipe tissues were wrapped in aluminum foil and packed and sealed in polyethylene bags until sample analysis.

Sample Analysis: Nicotine and TSNAs
Wipe tissues were extracted for 3 h with 60 mL methanol solution spiked with 40-nicotine as an internal standard. Nicotine was analysed by GC-MS. For this, an aliquot of 20 mL of the extraction solution was evaporated, residues reconstituted in methanol and the filtered extracts transferred into auto sampler vials for analysis on a Thermo Scientific TRACE gas chromatograph with a single-quadrupole mass spectrometer. The chromatographic separations were carried out using a Restek RTx-35 column (30 m x 0.25 mm ID; 1 µm film). Helium (constant flow: 1 mL/min) was used as carrier gas. Oven temperature started at 50 °C and after 2 min was increased by 10 °C/min up to 250 °C. The final temperature was held for 15 min. The mass spectrometer operated in the selective ion monitoring (SIM) mode. For nicotine quantification, m/z 161 was used. Identification was performed by retention time and specific compound mass.

Results were calculated as nicotine deposited on surface area of 1 m² (µg/m²).

NNK (a general marker for TSNAs) was analysed by LC-MS/MS from an evaporated aliquot of the extraction solution. The residues were dissolved in 50% methanol and the filtered extracts were transferred into auto sampler vials. Analysis was conducted using an Agilent 1200 liquid chromatograph coupled with an API 6500 triple quadrupole mass spectrometer with positive electrospray ionization from AB Sciex. A Phenomenex Gemini C18 column (3 µm, C18, 110 Å, 150x4.6 mm) was used for LC separation. Analysis was carried out using a gradient elution, in which the mobile phase composition of 50% (water/methanol with 0.1% formic acid) was held for 4 min, changed to 10% in 1 min, maintained between 5-6 min and then changed to the initial composition between 7-11 min. The flow rate was 0.6 mL/min. For quantifying, the multiple reaction monitoring (MRM) transition of the [M+H]+ of NNK at m/z 208 → 123 products. NNK at 210 → 126 were assayed. The m/z 208.1 – 78.9 transition was used as qualitative ion pair.

Results were calculated as NNK on surface area of 1 m² (ng/m²); limit of detection, 77.8 ng/m².

3. No Increase in Surface Nicotine Levels Detected After E-Cigarette Use

- During the vaping period, users collectively took 322 puffs for the closed system product and 339 for the open system product, as determined by video recording of the experiments.
- Samples taken prior to e-cigarette use indicated the presence of trace levels of nicotine. This was unsurprising, as nicotine has been reported to be widely occurring in the build environment [5,6].
- There was no measurable increase in the levels of nicotine detected on the surfaces 40 min or 24 h after use of the closed and open system e-cigarettes. The average concentration of nicotine detected on the walls and desk during each test phase for both e-cigarette products was <1.5 µg/m². As nicotine is not evenly distributed on the surfaces tested, it is not possible to interpret any differences in nicotine-smoke presence in the environment.
- During each test phase for both e-cigarette products, there was no detectable levels of NNK on the surfaces analysed; all samples were below the limit of detection.

4. Conclusions

- Using the closed or open system e-cigarette products tested in this study did not lead to a measurable increase in nicotine levels on the surfaces analysed. This is consistent with previous reports that e-cigarette users exhaled negligible levels of nicotine into ambient air which may be attributable to the high retention rate of nicotine in the user’s body [7]. Moreover, NNK (a general marker for TSNAs) could not be detected on the surfaces analysed at each test phase.
- The results supported the recent pilot study observations of Bluh and Gioniewicz [8] that nicotine in ambient air was not a risk to non-users’ homes in real-life settings [6].
- Interestingly, when Gioniewicz and Lee (2014) released machine generated e-cigarette aerosols into an exposure chamber, an increase in the amount of nicotine deposited on various surfaces was detected [8]. This is to be expected since there is 0% nicotine retention and 100% release of nicotine to the ambient air. It is therefore questionable to compare results from machine generated aerosol released into a room with aerosol generated from human subjects when assessing so-called “third-hand exposure” to e-cigarette emissions.
- Under the conditions of this study, our results indicate that there is little evidence of nicotine deposition on surfaces from use of the e-cigarettes tested and is unlikely to pose an issue to bystanders.
- The results presented here relate to a typical closed and open (tank) system e-cigarette and may not be generally applicable to other products such as Advanced Personal Vaporizers (‘MODs’) due to potential differences in vapour behaviour, aerosol properties and technologies. Further research with different product types is critical in different settings with different volunteer groups is planned.

References, Declaration of Interests & Acknowledgments

We would like to thank Special Analytica Laboratory at Imperial Brands plc for their assistance with sample analysis.

An Assessment of Nicotine Levels on Office Surfaces Before and After Use of Electronic Cigarettes

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Society for Research on Nicotine & Tobacco (SRT) Annual Meeting
Florence, Italy, 2017

1290 Nicotine and Tobacco Research (2016) 20:1290–1296
8 NNK (N-nitrosonornicotine) is a potential human carcinogen.
9 A study conducted by the U.S. National Cancer Institute (1986) indicated that NNK exposure results in increased liver tumors in rats.
10 Nicotine, the psychoactive component of tobacco, is derived from the leaves and is primarily responsible for the characteristic properties of tobacco including its addiction potential.
11 The prevalence of smoking has been declining over the past few decades, and with this decline, smoking in the workplace has decreased.
12 Similar results have been found in the general population (both smokers and non-smokers).
13 The U.S. National Cancer Institute (1986) reported that NNK exposure results in increased liver tumors in rats.
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17 This is because NNK is a potent mutagen, and its presence in tobacco products is a significant endogenous source of NNK.
18 The U.S. National Cancer Institute (1986) reported that NNK exposure results in increased liver tumors in rats.
19 similarity to the common e-liquid nicotine level of 1.8%.