Aerial transmission of the SARS-CoV-2 virus through environmental e-cigarette aerosol: is it plausible?

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Abstract

We discuss the implications of possible contagion of COVID-19 through e-cigarette aerosol (ECA) for prevention and mitigation strategies during the current pandemic. This is a relevant issue when millions of vapers (and smokers) must remain under indoor confinement and/or share public outdoor spaces with non-users. The fact that the respiratory flow associated with vaping is visible (as opposed to other respiratory activities) clearly delineates a safety distance of 1-2 meters along the exhaled jet to prevent direct exposure. Since vaping is a relatively infrequent and intermittent respiratory activity with emission rates comparable to mouth breathing (between 2 and 230 droplets per puff), it adds into shared indoor spaces (home and restaurant scenarios) a 1% extra risk of indirect COVID-19 contagion with respect to a "control case" of existing unavoidable risk from continuous breathing. As a reference, this added relative risk increases to 44-176% for speaking 6-20 minutes per hour and 260% for coughing every 2 minutes. Mechanical ventilation, universal wearing of face masks and outdoor conditions produce marginal changes of these relative risk estimations. As a consequence, protection from possible COVID-19 contagion through vaping emissions does not require extra interventions besides the standard recommendations to the general population: keeping a social separation distance of 2 meters and wearing of face masks.

1. Introduction

Direct aerial transmission of the SARS-CoV-2 virus through respiratory droplets across short distances is a fact acknowledged by the public health community and ratified by the WHO and the CDC [1]. Indirect transmission across larger distances by smaller droplets (often referred to as '*aerosols*' *) has also been observed (especially in hospital wards [2]), but its scope and frequency remain controversial [3,4,5]. The current COVID19 pandemic has intensified scientific interest in the existing comprehensive scientific literature on aerial pathogen transmission, mechanisms of respiratory droplet generation, viral transport and dynamics of respiratory droplet emitted by different respiratory activities, such as respiration [6], vocalization [7], coughing [8] and sneezing [9].

In most jurisdictions, the early observation of aerial contagion and delay in testing, along with precedents from previous pandemics, prompted a response to the COVID-19 pandemic focused on containment policies, including compulsory domestic confinement in the form of complete or partial lockdowns, closure of non-essential enterprises, restaurants, colleges, leisure activities, mass gatherings. More than 4.5 billion people were confined by April (approximately 58% of the world's 7.79 billion population by 2020, projected by the United Nations)[10] and nearly 2.7 billion jobs were lost (approximately 81% of the world's workforce)[11]. As economies have partly reopened, involuntary confinement has been relaxed, but most jurisdictions retain different degrees of economic activity limits with varying social contact limitations (for a review of global public policies see [12]).

The social effects and rapid changes associated with the COVID-19 pandemic have produced specific psychosocial problems that have had an effect on the mental health of the population living under these strict steps. Forced isolation has contributed to anxiety, depression and a rise in the intake of psychoactive stimulants, alcohol, cigarettes and nicotine products in certain individuals to alleviate tension and negative feelings [13]. These situations provide a framework to understand the need for evidence-based arguments to address relevant issues on smoking and vaping in the context of the COVID-19 pandemic.

There is an extensive literature on aerial pathogen transmission through respiratory activities and this transmission of the SARS-CoV-2 virus has been documented [2,3,4,5,6,7,8,9]. However, there is no empiric evidence (nor previous proper research[**]) of aerial transmission of the SARS-CoV-2 virus (or any pathogen) through environmental e-cigarette aerosol (ECA) or environmental tobacco smoke (ETS) exhaled by infected vapers or smokers. Concern on the hypothetic possibility of COVID-19 contagion through these routes is perfectly legitimate but needs to be placed in its proper context and be supported by direct or indirect evidence and/or sound scientific arguments. Regrettably, this legitimate concern has prompted some public health authorities to overreact by enacting smoking and vaping bans in outdoor public open spaces, as for example in Spain [17]. This is an overzealous and invasive protective measure which lacks evidence or scientific justification to support it.

In order to address the lack of prior research and evidence on potential SARS-CoV-2 transmission through exhaled ECA, a comprehensive study [18] was undertaken to assess rigorously and extensively its plausibility, scope and risks. In the present paper we consider the findings of this study as a crucial source of scientific knowledge to contribute to set up guidelines for public policies on vaping and smoking in the context of containment, prevention and mitigation strategies in the COVID-19 pandemic. We believe this is a relevant mission, given the fact that these policies affect millions of vapers and smokers (and those around them), who need to share indoor and outdoor spaces at varying levels of home confinement and mobility constraints.

The following disclaimers must be issued: this article does not deal with health risks or potential hazards resulting from exposure to ECA that are not specifically linked to its exhalations transporting respiratory droplets that potentially might contain pathogens. While our main interest is focused on the effects of possible SARS-CoV-2 transmission through exhaled ECA, under certain nuances some aspects of our assessments and discussion apply to ETS (see section 5).

* We avoid in this paper denoting respiratory droplets as "droplets" (if their diameter is larger than 5 mm) vs "aerosols" (diameter smaller than 5 mm). Unless stated otherwise, the term "droplets" will denote respiratory droplets of any diameter

** A search of the literature produced three references [14,15,16]. These are short opinion pieces lacking a proper elaborate scientific analysis

2. **Smoking and vaping as risk factors for COVID-19**

The current pandemic has raised legitimate questions about the association between smoking and vaping vs infection among vapers and smokers and the various stages of COVID-19 related disease. Therefore, besides the possibility of being transmission vectors (which has not been investigated), it is also necessary to review the literature investigating smoking and vaping as risk factors for COVID-19 and how smokers and vapers cope under the specific conditions of the pandemic.

The WHO [19] and several studies [20,21,22] have identified smoking as a risk factor for COVID-19 by. This is a rational assumption, as smoking is a major factor leading to reported vulnerability conditions for COVID-19, such as cardiovascular ailments, diabetes or chronic lung disease [23,24]. While several studies [25,26,27] have shown a significant under-representation of smokers among subjects diagnosed with COVID-19 admitted to hospitals, a systematic meta-analysis [28] has reported that few smokers are actually admitted to hospitals, but that once hospitalized they face a higher risk for severe outcomes than non-smokers. These findings have prompted research [29,30] to explore the possibility that nicotine may provide a protective effect by interfering with the biochemistry of viral infection or the deadly overreaction of the immune system, since more severe outcomes of hospitalized smokers might be consistent with their sudden termination of nicotine consumption once admitted to hospitals. However, there is also skepticism on the outcomes of studies showing underrepresentation of smokers among hospitalized patients [31,32], while the nicotine protective hypothesis remains so far untested. Therefore, the interrelation between smoking, nicotine and COVID-19 remains so far inconclusive.

Several sources have argued that vaping is also a risk factor for COVID-19 [33,34,35], mostly on the basis of very indirect evidence of lung inflammatory processes reported from in vitro research, animal models and physiological harms detected in pulmonary tissue extracted from small samples of human vapers, all of whom are former or current smokers (see [36] for a review of these studies and [37] for critical appraisal). To claim that these findings provide strong evidence that vaping is a risk factor for COVID-19 is inconsistent with the noticeable absence of vapers among hospitalized or seriously ill COVID-19 patients. In fact, as compared to reports of smoking and other comorbidities, vaping habits among hospitalized COVID-19 patients have not been collected up to this date in epidemiological studies.

A recent study by the University of Stanford [38], based on a self-reported internet survey collecting data among young people aged 13 to 24 years up to 14 May, reported that ever e-cigarette use (exclusive and dual use of tobacco cigarettes) increases five-fold their odds of a positive COVID-19 result in a PCR test with respect to never users. However, as a contrast, actual vapers have the same odds for a positive COVID-19 result as never users (thus suggesting lack of biological plausibility). Also, the extrapolation of the surveyed sample to the USA population weighed by the 2018 census is inconsistent with the number of tests performed in this age group at the time of the study (see [39] for criticism of this article).

There are very few studies on smoking/vaping consumer habits during the COVID-19 pandemic. The associations between vaping and self-reported diagnosed/suspected COVID-19 was examined recently by a research team from the University College London [40], based on cross-sectional data from the longitudinal online study of UK adults: the **HE**alth **BE**haviour during the **CO**VID-19 pandemic (HEBECO) study. They found no association between diagnosed/suspected COVID-19 among never, current, and ex-vapers. Other findings:

- Among recent ex-vapers, 17.4% quit vaping as precaution for COVID-19, but 40.7% considered taking up vaping again since COVID-19, mostly out of stress and boredom.
- Among current vapers: 50% did not change vaping habits, 40% increased consumption and 10% decrease consumption.

Another study on smoking and vaping habits under COVID-19 was conducted by an Italian team [41]. The study is based on a self-reporting internet questionnaire on a sample of 1925 participants: exclusive cigarette smokers, dual users of cigarette and e-cigarettes, dual users of cigarette and heated tobacco products, former smokers, exclusive users of e-cigarette, exclusive users of heated tobacco products and never smokers. The main findings are

- Dual users of cigarette and e-cigarette and exclusive cigarette smokers perceived that their daily consumption has slightly decreased.
- Most exclusive cigarette smokers have considered quitting but most exclusive e-cigarette users have not considered stopping the use of e-cigarettes.
- About one third of former smokers declared thoughts about starting to smoke again

In spite of their limitations (being cross sectional self-reported surveys), these studies illustrate how COVID-19 may contribute to the reinforcement of various intentions or behavioral trends. Many smokers continued to smoke, despite being aware of the harms from smoking (even ex-smokers declared intentions to smoke again). A continuous stream of troubling media reports and attempts by health authorities to discourage the use of e-cigarettes described as a COVID-19 risk factor [42], persuaded some vapers to consider stopping vaping or to decrease consumption, but a substantial number of vapers kept vaping and even increased consumption. These behaviors and behavioral patterns are likely to reflect a balance between fears of infection or serious illness (often fed by the media or health authorities[42]) and the need to cope with cravings and tension in pandemic circumstances. These are significant issues that require further research.

3. Exhaled ECA as a visible respiratory flow: direct exposure

The physical and chemical properties of exhaled ECA are essential to infer its capacity to transmit the SARS-CoV-2 virus through the transport of respiratory droplets. We include here a review of these issues. Readers interested in technical details are advised to consult [18] and references cited therein.

Since about 90% of inhaled ECA is retained by the respiratory system [43], ECA is a strongly air diluted aerosol, whose particulate phase is made of submicron liquid droplets (i.e. diameters below 1 mm) composed of propylene glycol (PG), vegetable glycerin (VG), nicotine and water [44], with similar composition for its gas phase. As opposed to the “airborne” pathogen transmission for other respiratory activities, vaping involves an “ECA-borne” transmission carried by a different fluid in which respiratory droplets would be accompanied by a far larger number of ECA droplets (bioaerosols particle numbers are in general far fewer than in non-biological aerosols [45]).

The diameter distributions of ECA droplets peak at submicron values [18]. This should also hold for respiratory droplets that would be transported by ECA (see next section). The few larger ECA and respiratory droplets leave the flow of the carrier fluid and follow ballistic trajectories, settling on the ground or depositing in surfaces. Having little inertia, submicron droplets follow the flow of the carrier fluid. Optical properties of liquid droplets in large numbers make the flow of ECA a visible cloud [45], *i.e.* the droplets act as visual tracers of the associated respiratory flow. In fact, aerosols with submicron droplets (like ECA) approximately evolve like gases with its particles behaving as molecular contaminants and are thus widely used to visualize respiratory flows [46] (even tobacco smoke has been used for this purpose [47]).

The fact that exhaled ECA offers an effective visualization of the expired flow distinguishes vaping (and smoking) from other respiratory activities potentially transmitting pathogens. This property has an important psychological dimension: bystanders seeing the expiratory flow potentially carrying pathogens can instinctively (without scientific training or computations) position themselves to avoid direct exposure, something impossible or very hard to do with other expirations. This is also relevant for safety and precautionary concerns, as visualization makes it absolutely clear that direct exposure risk distances are in the range 1-2 meters but only in the direction of the exhaled jet, with individuals placed in other directions (and not wearing face masks) only facing an indirect exposure risk. Nevertheless, it is prudent to maintain a 2 meters separation distance from everyone vaping if you don't wear a face mask.

The instinctive appreciation of the above-mentioned direct exposure distance and direction was corroborated in [18] by modeling exhaled ECA as an intermittent turbulent jet, made of ECA diluted in air, evolving into an unstable puff. As long as the exhalation lasts the jet trusts ECA and its accompanying respiratory droplets (which are also submicron, see next section) in the direction of its linear momentum. From estimated exhalation velocities between 0.3 m/s and 3 m/s and assuming a horizontal exhalation, the model predicts a distance reach for the exhaled jet/puff system between 0.5 to 2 meters.

The dynamical parameters inferred above assume the low intensity ‘mouth to lung’ (MTL) vaping style practiced by vast majority (80-90%) of vapers, involving a mouth hold before lung inhalation and using low powered devices (either starter kits, closed systems or pods). However, 10-20% of vapers practice the more intense ‘direct to lung’ style using high powered tank devices. As show in [18], this style involves larger exhalation velocities and distance spreads of over 2 meters. In this paper we will only consider the MTL style, as it is the most representative of vapers worldwide.

Another factor that needs to be considered is the potential effects on respiratory droplets due to the bactericidal and virucidal properties of glycols contained in ECA, such as PG and VG, which have been tested experimentally. A review of the data (see [18]) reported in these experiments indicates that environmental disinfection by these glycols is unlikely to occur under typical e-cigarette use conditions. Also, there is no experimental evidence that disinfection by these glycols would work on the SARS-CoV-2 virus. There is also no experimental evidence that disinfection of the SARS-CoV-2 virus by these glycols would work. Nonetheless, suitable studies should be established to assess this possibility even outside the context of vaping.

4. Indirect exposure

Once the fluid injection terminates (exhalation ends) the ECA jet becomes a roughly ellipsoidal puff that is rapidly disrupted by turbulent mixing from entrained surrounding air, with the trusted ECA and respiratory droplets drifting to the surroundings, carried by indoor air currents and remaining buoyant for long times (hours), thus leading to indirect exposure. To estimate indirect exposure through droplet dynamics it is necessary to incorporate into the model the effects of turbulent air mixing and thermal convection, as well as (ideally) more realistic conditions, such as a ventilation regime, heat emission from people and furniture and moving sources, all of which requires more advanced theoretical modeling and computational methods of fluid mechanics (as for example in [48]). Instead, we examined indirect exposure through a simplified exponential risk model based on the rates of expired viral load through various respiratory activities of actual SARS-CoV-2 data.

4.1 Respiratory droplets that should be carried by vaping

To evaluate indirect exposure risk from expiratory activities we need observational data on their expired volume, rates of respiratory droplet emission and droplet diameters. This data exists for breathing, vocalizing, coughing and sneezing, but not for vaping and smoking. Given the lack of experimental evidence on these parameters for exhaled ECA, we need to resort to appropriate respiratory proxies that resemble vaping and on which such evidence exists. To accomplish this task we undertake the following steps (see [18] for details):

1. We examine the data on respiratory mechanics of cigarette smoking as a proxy to infer and estimate the exhaled volume and other respiratory parameters of vaping. This is justified, as most vapers are ex-smokers or current smokers,
2. Since vaping involves mouth inhalation by suction through a mouthpiece, we review the available literature on the effects of the inspiration/expiration routes and of mouthpieces and nose clips on respiratory mechanics.
3. Considering the data from the previous steps, we evaluate the exhalation velocities associated with vaping and notice that they are comparable to measured velocities of mouth breathing. This suggests that mouth breathing can be considered as an appropriate proxy to estimate droplet emission from vaping.

The data from cigarette smoking and mouth breathing gathered by these steps suggests that vaping should:

- release on average a tidal volume of 700-900 cm^3 exhaled ECA diluted in air,
- produce low emission rates: 2-230 respiratory droplets per puff, overwhelmingly in the submicron range (hence, they should be really droplet nuclei as droplets of this size evaporate instantaneously once exhaled).

Submicron respiratory droplet nuclei possibly transported by ECA fall in the range of diameters denoted in medical literature as “aerosols”. There are claims that these small droplets might play an important (so far unaccounted) role in spreading the SARS-CoV-2 virus [49,50], as there is evidence that this spread has occurred [2] and it is known (from droplet dynamics) that they remain buoyant for long periods (hours) and drift long distances (meters). These claims could be further supported by the detection of SARS-CoV-2 viral RNA in ventilation systems of hospital rooms [51], as well as by experimental evidence showing that SARS-CoV-2 virus in aerosol droplets remains viable and stable for 3 hours [52]. However, these were highly idealized experiments in which the artificially generated bioaerosol is unlikely to be an accurate simulation of droplets (especially small ones or their nuclei) generated in the respiratory system. Their airborne evolution in closed chambers might be unrepresentative of realistic conditions in indoor and outdoor environments. Also, detected RNA of SARS-CoV-2 does not necessarily indicate the presence of a viable infectious virus [53]. Therefore, the scope and frequency of COVID-19 contagion from this type of droplets (which would be the type transported by ECA) remain controversial (see [4,5])

4.2 Relative risk model

Given the parameters inferred above, we assessed in [18] the risk of SARS-CoV-2 contagion through indirect exposure to respiratory droplets by means of a simplified adaptation (which incorporates vaping) of the exponential dose-response reaction model of Buonanno, Morawska and Stabile, henceforth BMS [54] (see also [55]). BMS base their analysis on the notion of an infective quanta: the droplet dose necessary to infect 63% of exposed individuals, with the basic quantity defined as the rate of emitted quanta per hour ER_q, proportional to the viral load (RNA copies per mL) taken from collected data on the SARS-CoV-2 virus, the total volume of exhaled droplets (in mL), the breathing frequency and the exhalation rate. To evaluate ER_q for different expiratory activities, MBS use available observational data on emission rates and droplet diameters for breathing and speaking, which we adapt for vaping.

However, ER_q also depends on the duration of the expiratory activity. Breathing involves low amounts of emitted quanta, but it carries on continuously and is not suspended while people talk or cough, and also when they vape or smoke. Talking and coughing emit significantly higher values of ER_q than breathing, but are of short duration, while vaping is also of short intermittent duration and emits just slightly higher ER_q than breathing (but very close). Typically, vaping involves 160-200 puffs per day (in a 16 hours journey), which means 2 minutes employed in 10-13 breaths per hour among the roughly total average 600-1400 breaths per hour for average adults in rest breathing.

As a consequence of its low intensity and intermittent nature (each puff is roughly one breath long), vaping adds every hour just a minuscule (roughly 1%) increase of emitted quanta on top of those quanta emitted by continuous (unavoidable) rest breathing, which can be considered as the baseline “control” state. As a reference, normal speech for 6 minutes in one hour adds roughly 40% extra infective quanta over this control state.

BMS use an analytic expression for the exponential risk model and consider probability distributions and Montecarlo simulations to account for individual variability of infective parameters and susceptible individuals. Instead, we define in [18] a relative risk of indirect exposure with respect to the above-mentioned control state as the quotient of ER_q associated with a given expiratory activity with respect to ER_q for breathing, considering for every expiratory activity (speaking, coughing and vaping) the fraction of breaths per the hour it lasts. We also simplify the model of BMS by considering only mean values (50% percentiles) of their probability distributions. Under these assumptions, our quotient that defines the relative exposure risk provides a good approximation to the analytic expression of BMS and to the risk model of their earlier paper [55].

Assuming that the submicron respiratory droplets from vaping (and other expirations) have been spread uniformly and considering recent data used by BMS on SARS-CoV-2 viral load and other infection parameters, as well as their data on droplet size and emission rates and our adaptation of this data to vaping, we evaluated in [18] these relative risks for a home and restaurant scenarios (12 and 3 hours total exposure) with natural and mechanical ventilation. The resulting values of added risks computed with respect to the control case are:

- 1% for vaping (160 daily puffs, 16 hour journey)
- 44 % for continuous speaking 10 % of time (6 minutes every hour), up to 90 % for speaking 40 % of time (20 minutes every hour)
- over 260 % for coughing 30 times per hour.

Notice that these are relative risks with respect to a control state defined by continuous breathing without vaping, speaking or coughing. As a consequence, these results hold for both scenarios and ventilation regimes, though the absolute number of emitted quanta vary significantly depending on the exposure time, volume of indoor space, number of susceptible individuals and ventilation regime (natural and mechanical). We find that mechanical ventilation decreases absolute risk for indirect exposure by an order of magnitude for each activity.

4.3 Face masks

We did not assume universal wearing of face masks In the analysis of the previous subsection, but even at this lowest level of prevention and protection, the analysis of [18] shows that vaping adds only a minuscule additional risk (1%) to those risks already existing from continuous breathing. However, if infectious persons are wearing face masks, their emission of infective quanta can be effectively reduced, thus lowering (proportionally to the filtering ability of the mask) the level of the current baseline risk of continuous respiration, but bystanders wearing face masks are also shielded from emissions from infected persons who may not wear face masks [56,57].

It can be argued that vaping requires the temporary removal of the vaper’s face mask and thus will raise the relative risk of exposure because of the decrease of the baseline level when everyone is wearing a face mask. However, this increase of risk would be inconsequential because it would be offset by the fact that the same face masks worn by everybody else would shield them from droplet emissions produced in the short intermittent mask-free vaping episodes.

5. Vaping vs smoking

Like ECA, ETS (environmental tobacco smoke) is also an aerosol whose particulate matter lies overwhelmingly in the submicron range. However, its solid and liquid particles (the TAR: tobacco aerosol residue) and its gas phase are characterized by a considerably higher level of chemical complexity and toxicity than ECA gas phase and particles (droplets made of PG, VG, nicotine and water [44]). Unlike ECA, whose only source is the mainstream emission from the exhalation of the vaper, ETS has two sources: in addition to the mainstream emission from the exhalation of the smoker, approximately 80% of the aerosol mass emitted into the environment comes from the side stream emission from the cigarette's burning/smouldering tip [58].

As far as the characteristics of potentially carried respiratory droplets, distance for direct exposure and indirect exposure risks to SARS-CoV-2, the results obtained in [18] (summarized in previous sections) apply only to mainstream ETS, as side stream emissions do not come from the respiratory system. As a consequence, pathogen transmission (including SARS-CoV-2) is a truly minor issue among health hazards from indoor exposure to ETS.

We emphasize that mitigation and prevention policies must bear in mind that, aside for SARS-CoV-2 transmission, vaping and smoking in indoor spaces represent completely different exposure risks. Studies of exhaled ECA that express concern on health risks from exposure to its “particles” [59] or from their deposition in the respiratory system [60], often overlook the fact that these “particles” are liquid droplets made of low toxicity compounds: PG, VG, nicotine and water [44]. There is no evidence of harm to bystanders exposed to exhaled ECA derived from inhaling these droplets, which are not comparable with particulate matter of combustible sources like ETS or air pollution, even if their number densities and diameters might be comparable.

While ETS is a serious indoor pollutant (specially in poorly ventilated spaces), exhaled ECA poses negligible health risk to bystanders. This assessment follows not only from the much higher content of toxicants in the particulate and gas phases of ETS (especially side stream emissions), but from the duration of the exposure, a crucial factor that determines the total load of inhaled toxicants. Bystanders are exposed to exhaled ECA in indoor spaces for very short periods, as its mean life is 10-20 seconds per exhalation, while their exposure to ETS is of long duration with mean life up to 40 minutes per exhalation (see [61,62]). This significant difference follows from their distinct physicochemical properties: ECA droplets rapidly evaporate into the rapidly diluting and dispersing supersaturated gas phase. As a contrast, both phases of ETS have a large non-volatile content that does not evaporate, but ages and lingers long periods in the environment, with its solid and liquid particles slowly settling gravitationally or depositing in surfaces and walls [58].

6. Implications for prevention and containment policies

6.1 Home confinement

The home scenario is especially relevant to assess COVID-19 transmission from vaping and other expiratory activities during home confinement, which is the indoor scenario that has affected most of the population in the current pandemic at global scale. Home confinement is relevant, not only when containment measures have required a strict mandatory lockdown, but also under less strict conditions of a mitigating strategy which allows for a partial reopening of economic activity, but still advises the population to stay at home as long as possible.

The pandemic has been characterized by a broad geographical and temporal variance in the severity of conditions, with increasing rates of infection and hospitalization leading to restrictions on social and business practices, closure of restaurants, bars, shops and non-essential industries, both of which suggest a rise in the proportion of the population at least partially under home confinement. For example, this was reported in a survey conducted in New York City between September and November across 46 thousand data points, showing that 73.84 % of new COVID-19 cases come from in-home meetings, 7.81 % from healthcare delivery and just 1.43 % from bars and restaurants [63].

The home scenario fits the indoor conditions that large numbers of vapers and smokers (and their families) must endure for a range of large periods under home confinement in which face masks are not usually worn. The 2 meters separation to avoid direct exposure and the risk assessment for indirect exposure, summarized in previous sections, provide valuable contextual information for safety policies in this scenario. Vaping with the average frequency of 160-200 puffs in a 16 hour journey only adds a minuscule (∼ 1%) extra contagion risk by indirect exposure with respect to the control case scenario of continuous breathing. It is therefore crucial that preventive measures should take into account that recommending abstention from vaping at home merely produces a negligible improvement in protection, with the potentially undesired effect of increasing the level of stress and anxiety of vapers and their families under confinement. Containment and prevention strategies should also take into account that promoting abstinence from vaping at home makes no sense when speaking (whose abstinence is not advised by a sensible policy) exposes household members to a substantially greater increase in relative risk (44 % to 176 %for speaking 6 and 20 minutes every hour).

As we commented in section 5, containment and prevention measures must distinguish between exhaled ECA and ETS. While exposure to ETS under home confinement can be hazardous pollutant for vulnerable individuals (specially in poorly ventilated spaces), it is not an important transmission vector for COVID-19.

6.2 Restaurants and outdoor environments

The prohibition of vaping inside homes has not been proposed by prevention or containment strategies (it would be an extremely ineffective and invasive action that would not increase safety), though many jurisdictions have banned vaping in publicly shared indoor spaces before the current pandemic: restaurants, bars, malls, bus and train terminals, airports, etc. Vaping is typically tolerated outdoors and often in enclosed or open terraces adjacent to bars and restaurants, areas that may not be closed to the public under less extreme pandemic conditions.

The analysis of [18] was also applied to a restaurant scenario, with and without ventilation, describing restaurant indoors or partially covered terraces. In fact, our risk evaluation should remain qualitatively valid, even in outdoor spaces, because it involves a proportional comparison with a control state of continuous breathing that is affected in practically the same way by the same environmental parameters as vaping exhalations: ventilation level, air currents, wind velocity, relative humidity or temperature gradients.

As opposed to home scenarios where face masks are seldom worn, prevention and mitigation measures strongly encourage universal face mask wearing in all publicly shared indoor and outdoor spaces, a suggestion that is usually taken up by the public in most countries and regions with fair implementation. However, as we argued in section 4.3, universal mask wearing requires only marginal amendments in our risk evaluation. Although vaping involves momentary removal of the face mask in 10-15 breaths out of around 600-1400 breaths per hour (rest breathing), in these brief mask free emissions, bystanders will be shielded by their face masks from infective quanta emitted by an infected vaper.

Further, we remark that eating and drinking (like vaping) in a bar or restaurant terrace also require face masks removal, so the same reasoning mentioned above remains valid: breathing emissions due to these brief face mask removal episodes to drink, eat or vape, or even to take a brief rest from wearing the mask, would only imply for bystanders (already protected for wearing face masks) exposure to a small extra infective quanta emission and only for a very short time. Since face masks are not 100% efficient in blocking emitted droplets and their usage cannot be rigidly maintained and enforced 100 % of time in shared spaces, tolerating this extra exposure is unavoidable and even necessary for civilized coexistence. In the specific case of vaping, this implies a tolerance of emissions in the mask-free periods that would be of shorter duration than those for eating or drinking: likely no longer than 10 seconds roughly 10-15 times per hour (being free from this exposure for the remaining 600-1400 breaths by the vaper in the same hour).

Considering the points raised above, to prohibit vaping in fully open outdoor spaces has an even weaker justification than a ban in restaurant terraces. Unfortunately, the Inter-Territorial Council of the National Health System in Spain has precisely invoked in its positioning document [17] the need for protection of the public from COVID-19 contagion to justify a nationwide ban on smoking and vaping in all outdoor spaces (even fully open spaces) where an interpersonal separation distance of 2 meters cannot be guaranteed. The document further argues to justify this prohibition that smoking and vaping also involve contagion risks not related to aerial transmission, such as face-to-face or mask contamination or sharing or tampering with a device inserted in the mouth. However, the same risks are present while drinking or eating, and even out of fatigue and discomfort for prolonged mask wearing without participating in any specific activity. These risks are unavoidable and tolerated and can be easily tackled by hygiene prevention.

Spanish health authorities do not provide empiric evidence that actual COVID-19 contagion through vaping or smoking exhalations has occurred nor a coherent technical justification supporting its plausibility, but nevertheless they invoke the precautionary principle to justify the enforcement of this ban at least for the duration of the pandemic. As we demonstrate in this paper on the basis of our rigorous analysis in [18], the marginal extra risk to bystanders from the short intermittent periods of mask removal when vaping (and smoking) take place is offset by the protection that their face masks affords them in shared outdoor spaces where wearing them is compulsory. To target exhalations from vaping and smoking as especially dangerous contagion vectors is an extreme and invasive implementation of the precautionary principle that lacks any scientific basis derived from current knowledge on droplet dynamics and emissions of expiratory activities carrying the SARS-CoV-2 virus (or any other pathogen).

5. Conclusion

Since a significant number of vapers have quit smoking by taking up vaping, it is crucial that mitigation and prevention strategies do not lead to an environment (with or without confinement) that may cause these ex-smokers to relapse to smoking. This could happen if they (and/or their family members) become misinformed by exaggerated or misleading claims about vaping, like unsubstantiated claims that link vaping and COVID-19, or using the EVALI crisis that occurred in the USA in 2019 to claim that it is equally (or more) harmful than smoking. Vapers may also relapse to smoking if vaping shops are ordered to close while cigarettes remain accessible in convenience stores, as has happened in many jurisdictions [64,65,66] but not in others [67]. As commented before, cravings and anxiety can be undesired psychological byproducts of long term confinement and can increase consumption among smokers and vapers, or induce ex-smokers or ex-vapers to relapse. In this case, it is preferable to favor the increase of consumption or the relapse to e-cigarettes, the less harmful product.

It is true that vaping involves risks not relevant to aerial transmission, such as face-to-face or mask contamination or sharing or tampering with a device inserted in the mouth, but the same risks are present while drinking or eating (and are tolerated or tackled by hygiene prevention). The same tolerance and courtesy offered to people when drinking or eating should be granted to vapers, most of whom prefer to avoid smoking and remain smoke-free (or at least to smoke less). The risk for direct and indirect COVID-19 contagion from indoor vaping expirations does exist and must be taken into consideration. However, this risk must be understood with reference to its potential to transport respiratory droplets in the context of markers and parameters of other expiratory activities. Therefore, as far as protection against the SARS-CoV-2 virus is concerned, vaping does not require particular additional interventions, other than those already suggested for the general public, in the home scenario or in shared social spaces: social distance and face masks. Vapers should be advised to be alert to non-vapers' issues and worries while sharing indoor spaces or dwellings or when near to other residents, and to use low-powered devices for low-intensity vaping for safety measures. Vapers, however, deserve the same sensitivity, courtesy and tolerance.

Competing interests

RAS has no competing interests to declare.

EG is currently employed by Myriad Pharmaceuticals, an independent company that manufactures e-liquids and vaping devices in New Zealand. She also provides consultancy work on research and development, regulatory affairs support, and formulation to several independent vaping companies in the Pacific Region. In the past she has worked for several pharmaceutical companies, including GlaxoSmithKline and Genomma Lab. She is also a member of the standards committee of the VTANZ and UKVIA.

R.P. is a full-time employee of the University of Catania, Italy. RP is Medical Director of the Institute for Internal Medicine and Clinical Immunology at the Universiy of Catania, Italy. In relation to his work in the area of tobacco control and respiratory diseases, RP has received lecture fees and research funding from Pfizer, GlaxoSmithKline, CV Therapeutics, NeuroSearch A/S, Sandoz, MSD, Boehringer Ingelheim, Novartis, Duska Therapeutics, and Forest Laboratories. He has also served as a consultant for Pfizer, Global Health Alliance for treatment of tobacco dependence, CV Therapeutics, NeuroSearch A/S, Boehringer Ingelheim, Duska Therapeutics, Forest Laboratories, ECITA (Electronic Cigarette Industry Trade Association, in the UK), and Health Diplomats. RP has served on the Medical and Scientific Advisory Board (MSAB) of Cordex Pharma, Inc., CV Therapeutics, Duska Therapeutics Inc, Pfizer, and PharmaCielo. Lecture fees from a number of European EC industry and trade associations (including FIVAPE in France and FIESEL in Italy) were directly donated to vaper advocacy no-profit organizations. RP is also founder of: 1) the Center for Tobacco prevention and treatment (CPCT)

at the University of Catania; and 2) the Center of Excellence for the acceleration of Harm Reduction (CoEHAR) at the same University, which has received support from Foundation for a Smoke Free World to conduct 8 independent investigator-initiated research projects on harm reduction. He is currently scientific advisor for LIAF, Lega Italiana Anti Fumo (Italian acronym for Italian Anti-Smoking League) and Head of the European Technical Committee for standardization on “Requirements and test methods for emissions of electronic cigarettes” (CEN/TC 437; WG4).

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