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Real-Time Measurement of Alcohol Vapours Released from Alcohol-based Hand Disinfectants and User Habits Study of Hong Kong Residents in the Pandemic of COVID-19

Chui-Man Lo [1], Jie Han [2,*], Juan Zuo [3], Siu-Kan Law [2], Kwan-Yee Tang [2], Yat-Long Lau [2], Yat-Hei Fung [2], Chak-Him Chung [1,2], Wai-Tung Leung [2]

[1] Department of Chemistry, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong SAR
[2] Department of Science, School of Science and Technology, Hong Kong Metropolitan University, Ho Man Tin, Kowloon, Hong Kong SAR
[3] Fujian Provincial Key Laboratory of Functional Materials and Applications, Xiamen University of Technology, Xiamen 361005, P. R. China
* Correspondence: chan@hkmu.edu.hk (J.H.);

Scopus Author ID 57199890667

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Abstract: Based on the information suggested by World Health Organization (WHO) and Hong Kong Special Administrative Region (HKSAR) government, wearing a mask and sterilizing hands with alcohol-based hand disinfectants are effective ways to maintain good personal hygiene to prevent viral infections. This study focused on the real-time concentrations of alcohol vapor in the air associated with five alcohol-based hand disinfectants. The results indicated that the alcohol concentrations increased dramatically (max. ~46,000 ppb/g sample) in the hand-rubbing process. Hong Kong residents' survey on habits of using such disinfectants showed that 65% of people use them daily and 34% of people use them ≥ 5 times per day, indicating a high frequency of usage. About 79% of respondents claimed to have skin problems, and 18% got eyes discomfort when using these disinfectants. Despite the potential health risks of using alcohol disinfectants remaining unclear, such a large amount and frequent usage should be aware of potential health problems in the long term.

Keywords: alcohol-based hand disinfectants; volatile organic compounds; alcohol concentrations; indoor air quality; COVID-19.

1. Introduction

The pandemic of coronavirus disease (COVID-19) has been recognized as a global crisis in public health. Hong Kong was one of the most densely populated places in the world when the fifth wave of pandemics began on 31/12/2021, and the number of cumulative cases was over 1,200,000 as of 30/06/2022 (Figure 1) [1]. The situation is attributed to the increasing consumption of antiseptic products and personal protection equipment, especially hand soaps, blench solutions, alcohol-based hand disinfectants, and surgical masks. It is well proven that hand hygienic compliance can be improved by using alcohol-based hand disinfectants and hand soaps, which are essential for preventing bacterial or viral infections [2-11]. Recently, Kratzel *et al*. reported that the frequently used alcoholic ingredients, such as ethanol and isopropanol, in alcohol disinfectants recommended by the World Health Organization (WHO) are effectively inactivating the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the virus causing COVID-19 [12]. Thus, the application of alcohol disinfectants is highly recommended according to the disinfection guidance from WHO (2020) [13].

The major alcoholic ingredients in alcohol-based hand disinfectants, namely ethanol (ethyl alcohol) and 2-propanol (isopropyl alcohol), are kinds of volatile organic compounds (VOCs). VOCs can be emitted from various sources such as building materials, combustion processes, consumer products, and personal care products [14-17]. Exposure to high concentration VOCs may lead to irritation of the respiratory system, headaches, loss of coordination, and "sick building syndrome" due to poor air quality.

A combination of all VOCs is also named "Total Volatile Organic Compounds" (TVOC). The most common classification for TVOC is developed by the World Health Organization (WHO, 1989) [18]. It differentiates TVOCs according to their volatility (or boiling point) into Very Volatile Organic Compounds (VVOCs), Volatile Organic Compounds (VOCs), and Semi-volatile Organic Compounds (SVOCs). TVOCs are an important indication of indoor air quality regarding the organic compounds (such as ethanol and isopropanol) that occur inside.

The alcohol-based hand disinfectants are possible VOCs releasing agents due to the nature of easily evaporating alcohol-based ingredients and other related solvents. The main adverse effects of VOCs on humans include eye, nose, and throat irritation, headaches, loss of coordination, and nausea, as well as damage to the liver, kidney, and central nervous system (EPA (US) 2020) [19]. Although neither the guidance from EPA nor WHO and other authorities revealed that exposure to alcohol-based hand disinfectants is harmful to consumers, the consequence of their heavy and repeating usage should be aware. The active ingredients such as ethanol and isopropanol in alcohol-based hand disinfectants and their possible hazards to human health are discussed below.

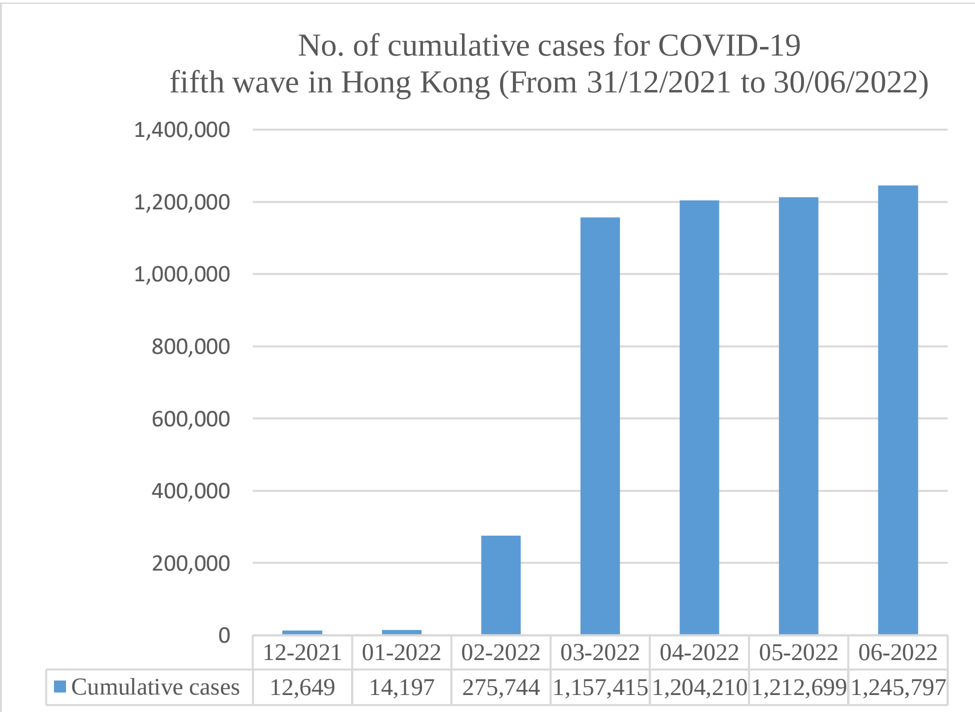

Figure 1. No. of cumulative cases for COVID-19 fifth wave in Hong Kong. (Data obtained from The Government of the Hong Kong Special Administrative Region).

1.1. Toxicity of ethanol and isopropanol.

According to the WHO in 2020, there are no harmful effects in using hand sanitizer for limited usage [20]. Daily usage discovered no toxic effects on the target organs such as the liver or the neurological, cardiac, and pulmonary systems. Although ethanol is not toxic to humans at low concentrations, chronic inhalation is still a concern of health issues, especially for the sensitive population. Ethanol, for instance, is harmful to the fetus as it can cross the placenta freely and arrive in the fetal blood [21-22]. In addition, inhaling a high concentration of ethanol causes respiratory irritation. The median lethal dose (LD_{50}) of ethanol in inhalation is 20,000 ppm for 10 hours, measured by the rat [23].

Besides, ethanol can irritate eyes and skin contact at high concentrations. The LD_{50} is 7,060 mg/kg in the rat for oral injection, and the LD_{50} toxicity of fish is 10,000 mg/L for 24 hours [24]. Its toxicity and related adverse effects of ethanol are the consequence of the metabolites, acetaldehyde, and the formation of reactive oxygen and nitrogen species capable of damaging DNA, amino acids, and lipids. Excess ingestion of alcohol is classified as carcinogenic according to the WHO International Agency for Research on Cancer [25].

Like ethanol, isopropanol can be absorbed through oral, dermal, and inhalational routes and enter the blood. 80% of isopropanol in the blood is metabolized via hepatic alcohol dehydrogenase to acetone and causes additional central nervous system depression. Then acetone is exported out through the urine. The remaining acetone is excreted through a pulmonary and salivary process [26]. However, ingesting isopropanol may lead to paralysis of the respiratory system, which frequently causes death. Previous findings also reported that the effects of isopropanol in the air at 97.5 mg/L could cause hypotension, respiratory minute-volume depression, and bradycardia in rats [27]. At high concentrations, isopropanol has a higher toxicity than the normal range. The LD_{50} in oral ingestion is 5,840 mg/kg body weight for 14 days (measured in rat), in inhalation is >10,000 ppm for 14 days (measured in rat), while in dermal adsorption is 16,400 mg/kg body weight for 14 days (measured in rabbit) [28]. Baikov *et al*. reported the chronic inhalation effects of isopropanol in rats, which experimentally tested the exposure of isopropanol to the rats at the concentration of 0.6, 2.5, and 20 mg/m^3 for 86 days, leading to a change in reflex behavior, increased in the total leukocyte count and abnormal fluorescent leukocytes [29].

In general, the lethal dose of isopropanol in oral ingestion for humans is in the range of 160-240 mL [30]. However, most studies on the toxicity of isopropanol are based on accidental ingestion instead of inhalation [31]. Some research studies on the exposure of isopropanol indicated its hazardous properties. Ballard *et al*. observed that the occurrence of illnesses including nausea, vomiting, and abnormal pain of the workers in a drug company can be attributed to the short-distance exposure of spilled carbon tetrachloride and isopropanol [32]. Most importantly, a previous study found that exposure to isopropanol vapor in 3-5 minutes and at concentrations of 200, 400, and 800 ppm also attributed to mild to moderate eyes, nose, and throat irritation, respectively [33]. On the other hand, some previous research showed that the manufacturing process of isopropanol by the strong-acid process is a possible contributor to cancers of the paranasal sinuses and laryngeal due to the formation of an intermediate substance, diisopropyl sulfate, in the strong acid process [34].

Some researchers have found that using alcohol-based hand disinfectants would release inhalable alcohol into the surrounding area. However, most of the studies regarding the inhalation of alcohol vapor are focused on the occupational exposure of healthcare workers

[35], and their risks or effects on general citizens still lack evidence to support or are even presumed negligible [36]. Consequently, incomplete assessments of the inhalation of alcohol may contribute to the loophole while ordinary people constantly apply a large amount of vaporizable alcohol-based hand disinfectants in daily life.

1.2. Measurement for total volatile organic compounds (TVOC).

Many methods have been described in the literature for measuring TVOC in air, such as using gas chromatography with flame ionization detection (GC-FID) and portable TVOC monitors. The portable TVOC monitor is used quite often for various studies because it can be carried and set up easily from place to place and can also provide real-time TVOC data at intervals of a few seconds with sensitivity in the range from ppb to ppm (RAE Systems: San Jose, CA, USA 2005) [37]. Some studies reported using portable real-time TVOC monitor with a photoionization detector (PID) to measure TVOC in different environments such as homes, offices, other indoor areas, and outdoor [38]. Jia *et al*. mentioned the use of high sensitivity PID to measure TVOC in retail stores [39]. Adeniran *et al*. reported using a Multi-RAE gas monitor to measure the exposure of TVOC from household spray products [40]. The detection range was 0-200 ppm with a resolution of 0.1 ppm. Apart from the application of PID, there were other methods for the measurement of VOC. For example, Noguchi M *et al*. reported the measurement of VOC in a newly built daycare center using thermal desorption-gas chromatography/mass spectrometry (ATD-GC/MS) [41]. Pei *et al*. reported the measurement of VOC in Chinese residences by gas chromatography-mass spectrometry (GC-MS) [42]. The indoor air samples were taken using a pump, desorbed by a thermal-desorbent using a cold trap with liquid nitrogen, and analyzed by GC-MS. However, as the analysis by GC-MS is comparatively time-consuming and is difficult to set up for onsite real-time measurement, thus it is not applicable in this project, and a portable TVOC meter was chosen.

Alcohol-based hand disinfectants in the form of liquid, gel, or foam, an alternative to hand soaps for antiseptic purposes, have mostly been adopted in hospitals and different medical institutions since the pandemic of SARS in 2003. Nowadays, alcohol-based hand disinfectants are easily purchased from various places, such as supermarkets, healthcare stores, and even online shops, leading to an obvious enlargement in consumption. Up to now, most of the studies regarding the health effect of inhalation of alcohol were conducted for healthcare workers, including doctors, nurses, and medical assistants. Research findings regarding the TVOC effects on frequently using alcohol-based hand disinfectants by the public remain limited, which cannot deduce its possible correlation with human health. In the present study, the concentrations of TVOC (alcohol vapor) were measured under a testing environment, simulating the condition when the individuals use alcohol-based hand disinfectants indoors. Moreover, a comprehensive survey was conducted about the usage habits of alcohol-based hand disinfectants of Hong Kong residents and related information. Data from the questionnaire and assessment of the TVOC in our experiment are subjected to further evaluation of indoor air quality (IAQ).

2. Materials and Methods

Five alcohol-based hand disinfectant samples in gel form were purchased from markets, such as supermarkets and healthcare stores were tested. Product information from their labels (e.g., origin, ingredients, and alcohol content) was recorded. Cap opening was also checked to prevent any blockages or defects that affected the sampling amount in the experiment.

The hand disinfection processes were conducted in a 2.9 × 7.5 m^2 room at The Hong Kong Metropolitan University (HKMU) with well-controlled temperature and humidity under the HVAC system. Room temperature and relative humidity were recorded before and after each time of hand rubbing by Q-Trak Indoor Air Quality Meter (Model and brand: TSI 7565x). The air velocity was measured by AirPro Velocity Meter (Model and brand: TSI AP500). A research volunteer was chosen to ensure the consistency of palms temperature and rubbing area throughout the experiment. The palm temperature was measured by a Meet® IR thermometer before applying the alcohol-based hand disinfectants.

A portable real-time Total Volatile Organic Carbon, TVOC meter (Model and brand: ppbRAE 3000) with PID equipped with a 10.6 eV UV lamp was used and placed one meter (100 cm) away from the volunteer's palm to measure the VOCs concentration. Before the measurements, calibrations were conducted by VOC Zeroing Tube and 10 ppm isobutylene gas from RAE Systems. The background of TVOC was measured before each data measurement. The TVOC meter was turned on for recording before opening the cap of alcohol-based hand disinfectants. A known amount of alcohol-based hand disinfectants (approximate 0.60 to 1.48 g) was poured on the palm, and the hands were rubbed following the hand hygiene technique recommended by the Centre for Health Protection (CHP) in 2017 [43]. The rubbing process took around 20-40 seconds until the palms were dried completely. Each alcohol-based hand disinfectant sample was measured in triplicate. The amount of alcohol used for each measurement can be calculated from the difference in the weight of the bottle before and after use (Figure 2).

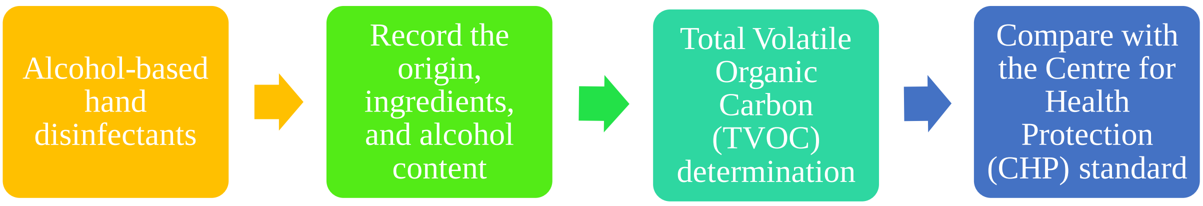

Figure 2. Flow chart of the experimental procedures.

3. Results and Discussion

The current study measured the alcohol vapors emitted from the 5 alcohol-based hand disinfectant samples as TVOC. In addition, the label information of alcohol-based hand disinfectants, including the origin, alcohol content, and ingredients other than the active ingredient, were summarized in Table 1. Besides the environmental condition, the average value of the volunteer's palms temperature, sample weight, and TVOC concentrations was summarized in Table 2.

With the comparison of the background reading (~130 ppb) and the TVOC response before and after applying the alcohol-based hand disinfectants samples, the concentrations of TVOC recorded were about 20600~47400 ppb/g higher than the background. Therefore, we conclude that the drastically increased TVOC concentration is mainly contributed by the major ingredient (i.e., alcohol vapors) when using alcohol-based hand disinfectants. The "Good Class" standard for TVOC in an indoor environment is 220 ppb for 8 hours in Hong Kong. Although the TVOC level obtained in this study cannot be compared directly with this standard, as the composition and duration of analysis are quite different, it can give us some insights into how high the alcohol vapor produced in the indoor environment when using the alcohol products. It was also noted that the bottle design of samples A~D and E are squeezed and pumped, respectively, which may cause a variation in the sample size and thus the sample weight.

Our experimental results undoubtedly showed a large amount of alcohol vapor emitted from the alcohol-based hand disinfectants during usage in a simulated environment. The use of practice may vary among people and depend on their social activities. There may be more than one person repeatedly using alcohol-based hand sanitizers in a small area such as offices. In addition, people may also use alcohol-based hand disinfectants to clean their hands in public transportation, supermarkets, and other indoor spaces, which may result in the accumulation of alcohol content. TVOC (alcohol) content indoors should consider the room size, the number of people, frequency, and amount of disinfectants used, especially regarding user habits. To clarify, a questionnaire was designed to investigate the habits of using alcohol-based hand disinfectants in Hong Kong residents.

Table 1. Information of alcohol-based hand disinfectant samples used in the experiment.

Sample (Assigned code)	Origin	Active ingredient	Alcohol content	Other ingredients
A	Hong Kong	Ethyl Alcohol	75%	Water, Glycerine, Propylene Glycol, Poly (acrylic acid), Triethanolamine
B	Hong Kong	Alcohol	60-70%	Purified water, Glycerine, Acrylates/C10-30, Alkyl Acrylate Crosspolymer, Fragrance
C	Hong Kong	Alcohol	65-75%	Water, PEG/PPG-17/6 Copolymer, Propylene Glycol, Limonene, Acrylates/C10-30, Alkyl Acrylate Crosspolymer, Tetrahydroxypropyl Ethylenediamine Aloe Barbadensis Gel, Fragrance
D	Hong Kong	Ethyl Alcohol	Unspecified	Water, Glycerine, Deionized water, Lonicera Japonica, Folia Llicis, Common Cnidium Fruit, Odourbark Cinnamomum, Rhizome Atractylodis, Fresh Ginger, Propylene Glycol
E	Hong Kong	Ethyl Alcohol	75%	Aqua, Glycerine, Vitamin E, Fragrance, Aloe Vera

Table 2. Environmental condition and alcohol measurement results.

Sample (Assigned code)	Average palms Temperature (°C)	Average weight of sample used (g)	Average maximum reading of TVOC (ppb)	Average maximum reading of TVOC (ppb) per 1g of sample
A	27.8	0.97	42,150	39,986
B	27.2	0.95	38,382	40,180
C	26.6	0.82	32,417	39,632
D	28.3	0.98	46,082	47,425
E	23.9	1.20	24,802	20,622

3.1. Questionnaires.

To maintain social distancing during the pandemic by government appeal and achieve an eco-friendly environment, a traditional paper survey was replaced by a bilingual online survey (Chinese/English). The questionnaires were distributed through various e-channels, such as Facebook, WhatsApp, WeChat, etc. More than 400 responses from different age groups with different education statuses were received. According to the results, most of the respondents (>94%) used alcohol-based hand disinfectants more frequently during the pandemic than before (Figure 3a). 92% of people bring a bottle of alcohol-based hand disinfectants (Figure 3b) when they are away from home to sterilize hands (96%), wipe their phones (53%), and even tables and chairs (18-35%) (Figure 3c).

65% of people use hand disinfectants daily (Figure 3d). The frequency per day is about 55% responses for 2-4 times, 25% for 5-10 times, and 9% even more than 10 times (Figure 3e). Respondents use alcohol-based hand disinfectants quite often in indoor areas, such as transportation (69%), restaurants (76%), and other places, including offices, markets, and hospitals (43-59% for each) (Figure 3f). Around 90% of respondents currently have more than 2 bottles of alcohol-based hand disinfectants stocked at home and office (Figure 3g). It indicated that alcohol-based hand disinfectants are essential to prevent the virus in the daily life of Hong Kong residents. For purchasing habits, respondents are more concerned about the concentration of alcohol (53%) and price (21%) when purchasing, and most of them choose 60-75% alcohol content for disinfection purposes (Figure 3h).

Hong Kong residents have good personal hygiene practices, resulting in the large consumption of alcohol-based hand disinfectants during the pandemic (Centre for Health Protection (Hong Kong) 2017). However, the frequent applications of alcohol-based hand disinfectants can contribute to the high concentration of VOCs and poor indoor air quality due to the highly volatile ingredients such as ethanol and isopropanol. Regarding the questionnaire results, the presence of discomfort symptoms, especially skin problems (79%), after alcohol-based hand disinfectants are statistically significant with the increasing frequency and intensity of alcohol-based hand disinfectants (Figure 3i). Although the mechanism of the positive correlation between the discomfort symptoms and the application quantities of alcohol-based hand disinfectants is still required to be clarified through further pharmacological research studies, our results coincidentally agree with a recent study of assessment of exposure to alcohol vapor during hand disinfection using two types of commercial alcohol-based hand disinfectants (ethanol and combined alcohols) [44-50]. This research showed that using alcohol-based hand disinfectants leads to the absorption of very low doses of alcohol. Still, repeated inhalation of high alcohol concentrations raises concerns about possible adverse health effects.

4. Conclusion

Considering the occurrence of COVID-19, the current study shows that alcohol-based hand disinfectants caused a dramatic increase in TVOC (alcohol vapor), up to ~46,000 ppb per gram on average. Although the active ingredients of alcohol-based hand disinfectants, ethanol or isopropanol, are termed safe when inhaled for a limited amount for long-term, the effect of frequent usage and the large quantity of application is not negligible, especially for some alcohol-based hand disinfectants contain preservatives and fragrances, etc., which might exert adverse health effects as well as indoor quality.

The frequent application of alcohol-based hand disinfectants leads to side effects, such as skin problems and throat or eye discomfort. We suggested putting some attention notes or warning labels on the alcohol-based hand disinfectants, especially for the elderly, pregnant women, children, or people who suffer from eczema or eye diseases. In addition, we suggest people try to use alcohol-based hand disinfectants in a relatively open area or enhance the ventilation if possible.

Hong Kong's government vigorously promoted knowledge of the importance of personal hygiene through TV programs and leaflets during COVID-19. After an investigation of our survey, we are glad to find that Hong Kong residents have already developed a good habit of using hand rubs and wearing masks, which the Hong Kong government encourages. We hope the pandemic of COVID-19 will be over as soon as possible.

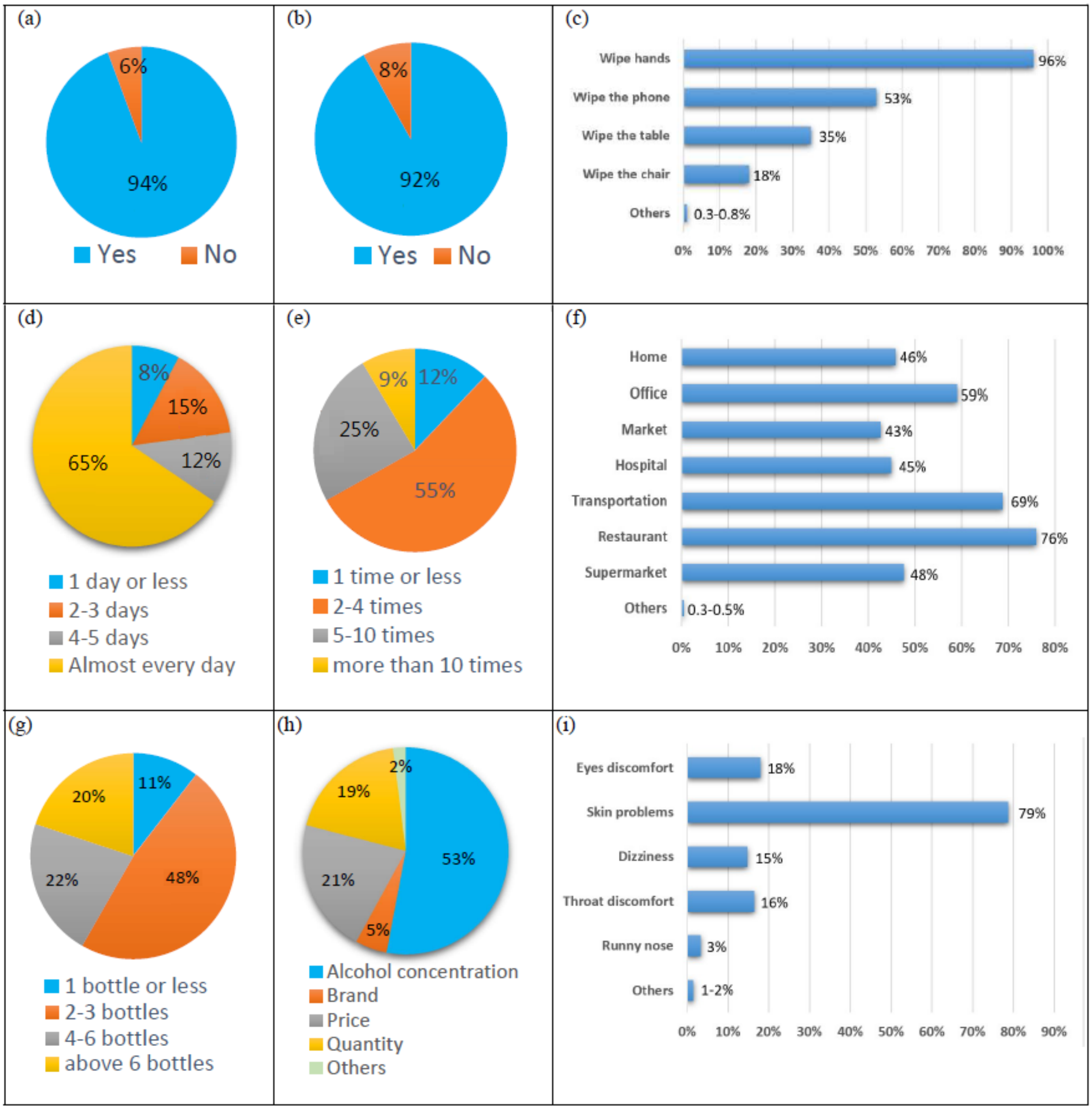

Figure 3. Some selected survey questions and feedback from (a) to (i): (a) Do you use alcohol-based hand disinfectants more frequently compared with the pandemic of COVID-19 before? (b) Do you bring a bottle of alcohol-based hand disinfectants when you go out? (c) Under what kinds of circumstances will the alcohol-based hand disinfectants be used? (d) How many days do you use the alcohol-based hand disinfectants per week? (e) How many times do you use alcohol-based hand disinfectants per day? (f) Where do you use alcohol-based hand disinfectants? (g) How many bottles of alcohol-based hand disinfectant(s) currently have in your home and office? (h) What is your major concern before buying alcohol-based hand disinfectants? (i) What are the symptoms when you or people nearby use alcohol-based hand disinfectants?

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Conflicts of Interest

The authors declare no conflict of interest.

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