Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Microfiber pillow as a potential harbor and environmental medium transmitting respiratory pathogens during the COVID-19 pandemic

ARTICLE INFO

Keywords
Coronavirus
Pneumonia
Transmission
Respiration
Saliva
Human airway

The number of infections by the novel coronavirus (SARS-CoV-2) continues to increase in many parts of the world. SARS-CoV-2 causes infections in human respiratory tract and spreads through breathing, talking, coughing, sneezing, and drooling (Yoon and Yoon, 2020). Among the everyday items, pillows are likely to be in close contact with user’s mouth and nose for several hours a day (CDC, 2017). During the current pandemic, people are advised to wear masks or alternative face coverings when they are in public, especially in areas of community transmission and settings where physical distancing is difficult to maintain (CDC, 2020a; WHO, 2020a). Wearing masks during sleep, however, may cause discomfort and difficulty in breathing (Shenal and Radonovich, 2012), and masks can easily fall off during sleep. As a result, pillows could be exposed to droplets exhaled from mouth and nose as well as saliva (e.g., from drooling), making them a potential harbor where SARS-CoV-2 could reside and accumulate.

Most contemporarily made pillows adopt a common design which consists of a fabric envelope with microfibers filled inside. Our survey on 100 products sold by major online retailers in the U.S. and mainland China showed that pillows with microfiber fillings are the most popular type (49%) among the U.S. and Chinese consumers (Table 1). Given the prolonged and close contact with human airways, respiratory pathogens can not only land on the cover, but may penetrate the fabrics, especially when people sleep on their stomach or side which increases the likelihood of drooling (Watson, 2019). Following a modified standard test procedure by the U.S. National Institute for Occupational Safety and Health (NOISH), Zhao et al. assessed several common household materials for respiratory protection (Zhao et al., 2020). The study found that cotton pillow cover and polyester cloth both exhibited high permeability (82%–95%) for NaCl aerosols below 0.1 μm. Konda et al. (2020) reported that aerosol permeability depended on both the particle size and the weaving density of fabrics. Specifically, cotton fabrics with a weaving density of 80 threads per inch showed high permeability (86% on one layer, 56% on two layers) for polydisperse NaCl aerosols in the range of 0.3–10 μm, with similar results (75%) obtained on the synthetic silk (i.e., polyester). Given that there are numerous microfibers packed inside the pillow, once the viruses travel through its surface, via exhalation or saliva, it will be difficult to achieve thorough disinfection by regular cleaning and disinfection methods such as spraying surfaces with disinfectants and laundering fabrics in warm water (CDC, 2020b; WHO, 2020a). It is particularly worth noting that, despite their proximity with human airways, current cleaning and disinfection protocols for aircrafts, trains, and lodging facilities do not make specific recommendations on pillows, such as their filling materials or envelopes, while focusing on surfaces, towels, and linens (CDC, 2020b; CDPH, 2020; WHO, 2020a). Meanwhile, studies have shown that SARS-CoV-2 could survive for hours to several days on fibrous materials under ambient conditions (Chin et al., 2020). A study on the Porcine Reproductive and Respiratory Syndrome Virus (PRRSV), an enveloped positive-sense single-stranded RNA virus as SARS-CoV-2, found that it could survive for 72 hours on polyester and cotton fibers on common tip swabs at 20°C (Fan and Gerber, 2019). Under the same temperature, Lai et al. (2005) found that it took 24 hours to inactivate SARS-CoV-1 on a cotton cloth inoculated with the virus at a TCID50 (Median Tissue Culture Infectious Dose) of 106 mL-1.

Although travel-related activities have considerably reduced, there are still needs for people to travel long distances (e.g., by plane, train) and use hotel accommodation in the current pandemic. Under the current protocols, these activities can be carried out normally for individuals who show no COVID-19 symptoms and wear masks or alternative face coverings (AIHA, 2020; AHLA, 2020; NRPC, 2020). Without being requested to present valid nucleic acid amplification test results for detection of SARS-CoV-2, however, it will be difficult to screen asymptomatic or pre-symptomatic individuals in those places. Although in some countries such tests have become mandatory for arriving passengers from international flights (CAAC, 2020; France Diplomacy, 2020), currently they are only required by certain countries and generally not needed for domestic travelers or hotel occupants showing no symptoms and having a normal body temperature. Temperature checks are recommended for guests at hotels, lodging, and short-term rentals in California (CDPH, 2020), while public health authorities in some other states in the U.S., the current epicenter of the COVID-19 pandemic, do not require such measure as per their latest

https://doi.org/10.1016/j.ecoenv.2020.111177
Received 26 June 2020; Received in revised form 10 August 2020; Accepted 12 August 2020
Available online 18 August 2020
0147-6513/© 2020 Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Guidelines (IDPH, 2020; VHIL, 2020). According to the industry-wide standards by the American Hotel & Lodging Association (AHLA), temperature checks or negative COVID-19 tests are currently not a required criterion for guest screening (AHLA, 2020). In the U.S., domestic travelers taking airplanes, trains, or automobiles face few restrictions, apart from the common requirement on wearing masks or alternative face coverings when using public transport (AFA, 2020; NRPC, 2020). Some states have started implementing travel orders which require domestic travelers and returning residents from certain parts of the country to quarantine for 14 days or present negative COVID-19 test results obtained within 72 hours upon their arrival (CT, 2020; MA, 2020).

The U.S. Centers for Disease Control and Prevention (CDC) estimated that 35% of COVID-19 patients in the United States do not show symptoms. Viral loads in the upper respiratory specimens of asymptomatic patients were found to be comparable to those of symptomatic patients, and asymptomatic patients also showed a strong ability to transmit the virus (Huff and Singh, 2020). The CDC has given specific precautions to the public on potential contact-route transmission of SARS-CoV-2 in public spaces, with a list of surfaces including tables, doorknobs, lights switches, keyboards, and touch screens (CDC, 2020b).

As a common sleep aid, pillows are provided on airplanes (e.g., in business-class cabins), couchette trains, and in various types of lodging facilities as reusable personal items. In an investigation between March 19–20, 2020, researchers examined the hotel rooms of two pre-symptomatic individuals and found that both of the occupants’ pillow covers accumulated high viral loads of SARS-CoV-2 within 24 hours of stay (Jiang and Jiang, 2020). Based on the timeline of events, those viruses survived for at least 3 h on pillow covers, although it was likely to be longer (<24 hours).

In accordance with recommendations by public health authorities (CDC, 2020b; WHO, 2020b), reusable items on airplanes, trains and in lodging facilities are regularly cleaned and disinfected during the current pandemic. While the removable covers or cases are routinely cleaned for reusable pillows, the efficacy of these methods in eliminating those viruses survived for at least 3 h on pillow covers, although it was likely to be longer (<24 hours).

Table 1

| Pillow fillings                      | Walmart.com (n = 25) | Amazon.com (n = 25) | Taobao.com (n = 25) | JD.com (n = 25) |
|-------------------------------------|-----------------------|---------------------|---------------------|-----------------|
| Microfibers (polyester)             | 14                    | 9                   | 13                  | 6               |
| Microfibers (other or unknown material type) | 2                    | 4                   | 1                   | 0               |
| Other materials (foams, down, gel, etc.) | 9                    | 12                  | 11                  | 19              |

Notes: Information on filling materials was compiled from product descriptions on various retailers’ websites. The best-seller designation of products was based on sales statistics published on retailers’ websites as of August 6–7, 2020, when our survey was conducted (Surveyed products, 2020).

Acknowledgements

This work was funded by the “Young Talent Support Plan” of Xi’an Jiaotong University. The authors wish to thank Xue Wang for her assistance in preparing the artwork appeared in the visual abstract.
Airlines for America (AfA), 2020. Major U.S. Airlines Announce Health Acknowledgment Requirement (June 29, 2020). https://www.airlines.org/news/major-u-s-airlines-announce-health-acknowledgment-requirement/. (Accessed 9 August 2020).

American Hotel & Lodging Association (AH&LA), 2020. Enhanced Industry-wide Hotel Cleaning Checklist & ‘Safe Stay’ Guest. https://www.ahla.com/safe-stay-member-resources. (Accessed 9 August 2020).

Civil Aviation Administration of China (CAAC), 2020. Presenting Negative Results of COVID-19 Nucleic Acid Tests before Boarding by Passengers Taking Flights Bound for China (21 July 2020). https://www.caac.gov.cn/en/XWZX/202007/t20200721_203702.html. (Accessed 9 August 2020).

Centers for Disease Control and Prevention (CDC), 2017. How Much Sleep Do I Need? https://www.cdc.gov/sleep/about_sleep/how_much_sleep.html. (Accessed 9 August 2020).

Centers for Disease Control and Prevention (CDC), 2020a. Considerations for Wearing Masks (updated August 7, 2020). https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/mask.html. (Accessed 9 August 2020).

Centers for Disease Control and Prevention (CDC), 2020b. Guidance for Cleaning and Disinfecting (updated July 22, 2020). https://www.cdc.gov/coronavirus/2019-ncov/community/clean-disinfect/index.html. (Accessed 9 August 2020).

California Department of Public Health (CDPH), 2020. COVID-19 Industry Guidance: Hotels, Lodging, and Short-Term Rentals (July 9, 2020). https://files.covid19.ca.gov/pdf/guidance-hotels-lodging-rentals.pdf. (Accessed 9 August 2020).

Chin, A.W.H., Chu, J.T.S., Perera, M.R.A., et al., 2020. Stability of SARS-CoV-2 in different environmental conditions. Lancet Microbe 1 (1), e10.

Connecticut State (CT), 2020. Travel Advisory for Visitors to Connecticut. https://portal.ct.gov/Coronavirus/travel. (Accessed 9 August 2020).

Fan, J., Gerber, P.F., 2019. Porcine reproductive and respiratory syndrome virus RNA detection in different matrices under typical storage conditions in the UK. Vet. Rec. 185 (1), 21.

France Diplomacy, 2020. Coronavirus - Advice for Foreign Nationals in France, Decree No. 2020-860 (updated 29 July 2020). https://www.diplomatie.gouv.fr/en/comin-nolett.0c02211. (Accessed 9 August 2020).

Huff, H.V., Singh, A., 2020. Asymptomatic transmission during the COVID-19 pandemic and implications for public health strategies. Clin. Infect. Dis. https://doi.org/10.1093/cid/ciaa654.

Illinois Department of Public Health (IDPH), 2020. Preventing COVID-19 Spread in Communities: Hotels Guidance (updated 30 June 2020). https://www.dph.illinois.gov/topics-services/diseases-and-conditions/diseases-a-z-list/coronavirus/preventing-spread-communities/hotels. (Accessed 9 August 2020).

Jiang, F.C., Jiang, X., 2020. Detection of severe acute respiratory syndrome coronavirus 2 RNA on surfaces in quarantine rooms. Emerg. Infect. Dis. 26 (9) https://doi.org/10.3201/eid2609.200435.

Konda, A., Prakash, A., Moss, G.A., et al., 2020. Aerosol filtration efficiency of common fabrics used in respiratory cloth masks. ACS Nano 14 (5), 6339-6347.

Lai, M.Y.Y., Cheng, P.K.C., Lim, W.W.L., 2005. Survival of severe acute respiratory syndrome coronavirus. Clin. Infect. Dis. 41 (7), e67-e71.

Commonwealth of Massachusetts (MA), 2020. COVID-19 Travel Order. https://www.mass.gov/info-details/covid-19-travel-order. (Accessed 9 August 2020).

Moltó, J., Font, R., Conesa, J., 2006. Study of the organic compounds produced in the pyrolysis and combustion of used polyester fabrics. Energy Fuel. 20 (5), 1951–1958.

Ministry of Railways (MoR) of China, 1994. Regulations for Railway Passenger Transport, Clause 103 (in Chinese). http://www.chinalawedu.com/falvfgui/fg2598/38573.html.

National Railroad Passenger Corporation (Amtrak), 2020. Amtrak Requires All Customers and Employees Wear Face Masks. https://www.amtrak.com/planning-booking/policies/coronavirus.html. (Accessed 9 August 2020).

Reisen, F., Bhujel, M., Leonard, J., 2014. Particle and volatile organic emissions from the combustion of a range of building and furnishing materials using a cone calorimeter. Fire Saf. J. 69, 76–88.

Russell, K.L., Broderick, M.F., Franklin, S.E., et al., 2006. Transmission dynamics and prospective environmental sampling of adenovirus in a military recruit setting. J. Infect. Dis. 194 (7), 877–885.

Shenal, B.V., Radonovich, L.J., 2012. Discomfort and exertion associated with prolonged wear of respiratory protection in a health care setting. J. Occup. Environ. Hyg. 9 (1), 59–64.

Surveyed products, 2020. https://www.walmart.com/browse/home/pillows/4044539103. (Accessed 9 August 2020).

World Health Organization (WHO), 2020a. Advice on the use of Masks in the Context of COVID-19: Interim Guidance (5 June 2020). https://apps.who.int/iris/handle/10665/32293. (Accessed 9 August 2020).

World Health Organization (WHO), 2020b. Cleaning and Disinfection of Environmental Surfaces in the Context of COVID-19: Interim Guidance (15 May 2020). https://apps.who.int/iris/rest/bitstreams/1277966/retrieve. (Accessed 9 August 2020).

Woodcock, A.A., Steel, N., Moore, C.R., et al., 2006. Fungal contamination of bedding. Allergy 61 (1), 140–142.

Yacht, B., Sultan, G., Liew, A., et al., 2020. The possible role of reusable pillows in hospital acquired infections. J. Infect. Med. 68 (4), 939.

Yoon, J.G., Yoon, J., 2020. Clinical significance of a high SARS-CoV-2 viral load in the saliva. J. Kor. Med. Sci. 35 (20), e195.

Zhao, M., Liao, L., Xiao, W., et al., 2020. Household materials selection for homemade cloth face coverings and their filtration efficiency enhancement with triboelectric charging. Nano Lett. 20 (7), 5544-5552. https://pubs.acs.org/doi/10.1021/acs.nanolett.0c02211.

Jie Han*, Yue Zhang
Department of Environmental Science and Engineering, Xi’an Jiaotong University, Xi’an, 710049, PR China
* Corresponding author.
E-mail address: jiehan@xjtu.edu.cn (J. Han).