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Study on the Use and Efficacy of Face Masks for Combating COVID-19 Transmission

APEC Life Sciences Innovation Forum

December 2023

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APEC Project: LSIF 01 2021

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APEC#223-HT-01.3

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Final Report

Study on the Use and Efficacy of Face Masks for Combating COVID-19 Transmission

Introduction

The emergence of the COVID-19 pandemic has reshaped our world in unprecedented ways, placing face masks at the forefront of essential tools in containing the virus's spread. This past year has witnessed an explosion of scientific research and community-driven initiatives focused on the development and evaluation of advanced face mask technologies. While these endeavors offer promise, they have also generated a vast body of data riddled with gaps, contradictions, and intricacies. To navigate this intricate landscape, we first initiate a systematic and comprehensive review of face masks. Our aim is to establish a comprehensive foundation for understanding the current landscape of face mask technologies, encompassing filtration mechanisms, fabrication techniques, filtration performance, and the advent of antimicrobial face masks.

Following this review, a community survey has been conducted to obtain firsthand information on the use and efficacy of face masks in China and Hong Kong, China. This survey is dedicated to uncovering people's habits of using face masks and their perceptions of their efficacy. It also sought to shed light on public awareness of the environmental challenges posed by the proliferation of discarded face masks, an issue still prevalent worldwide. Additionally, the survey aims to gauge public acceptance and perspectives on the future development of new mask technologies. This comprehensive survey adopts a questionnaire-based methodology, with 6 distinct sections comprising 74 questions. A total of 934 valid responses were collected through an online platform.

As a culmination of this multifaceted research journey, an Online Seminar was organized, open to APEC economies, with no participation fees. The seminar was designed to amplify the impact of our study, inform relevant policymakers, and promote the adoption of new face masks within society.

In conclusion, our efforts encompass a systematic review of face masks, a community survey, and an inclusive Online Seminar. This comprehensive approach enables us to explore and address the multifaceted challenges and opportunities presented by face masks during the COVID-19 pandemic, with the ultimate goal of contributing to the effective adoption of new mask technologies and the promotion of public health.

Literature Review

This section is a comprehensive endeavor aimed at systematically reviewing the state-of-the-art technology of face masks from both scientific and community perspectives. With the onset of the COVID-19 pandemic, a surge of research papers has been published over the past year, focusing on the development of new face mask technologies and the evaluation of their effectiveness across various regions. However, the reported data often exhibit significant gaps and, at times, yield contradictory results, thereby impeding the development and widespread utilization of face masks. In light of these challenges, there is a critical need for a systematic and in-depth review to shed light on the efficacy of face masks.

The effectiveness of face masks as a critical tool in safeguarding individuals from airborne contaminants has been the subject of extensive research and innovation. This literature review aims to provide a comprehensive overview of the key aspects pertaining to face masks, including their filtration mechanisms, fabrication methods, filtration performance, and the emergence of antimicrobial face masks. Additionally, it delves into novel mask technologies that have been developed to address existing limitations and enhance user protection.

This literature review provides a foundation for understanding the multifaceted world of face masks and offering valuable insights into various aspects. This knowledge serves as a crucial resource for making informed decisions regarding the selection and utilization of face masks across diverse contexts.

Filtration mechanisms

Face mask filtration efficiency hinges on a multitude of fundamental mechanisms, each operating within specific parameters dictated by particle size and environmental conditions (**Figure 1**). In this section, we explore these pivotal mechanisms and their roles in obstructing the passage of airborne particles through face masks.

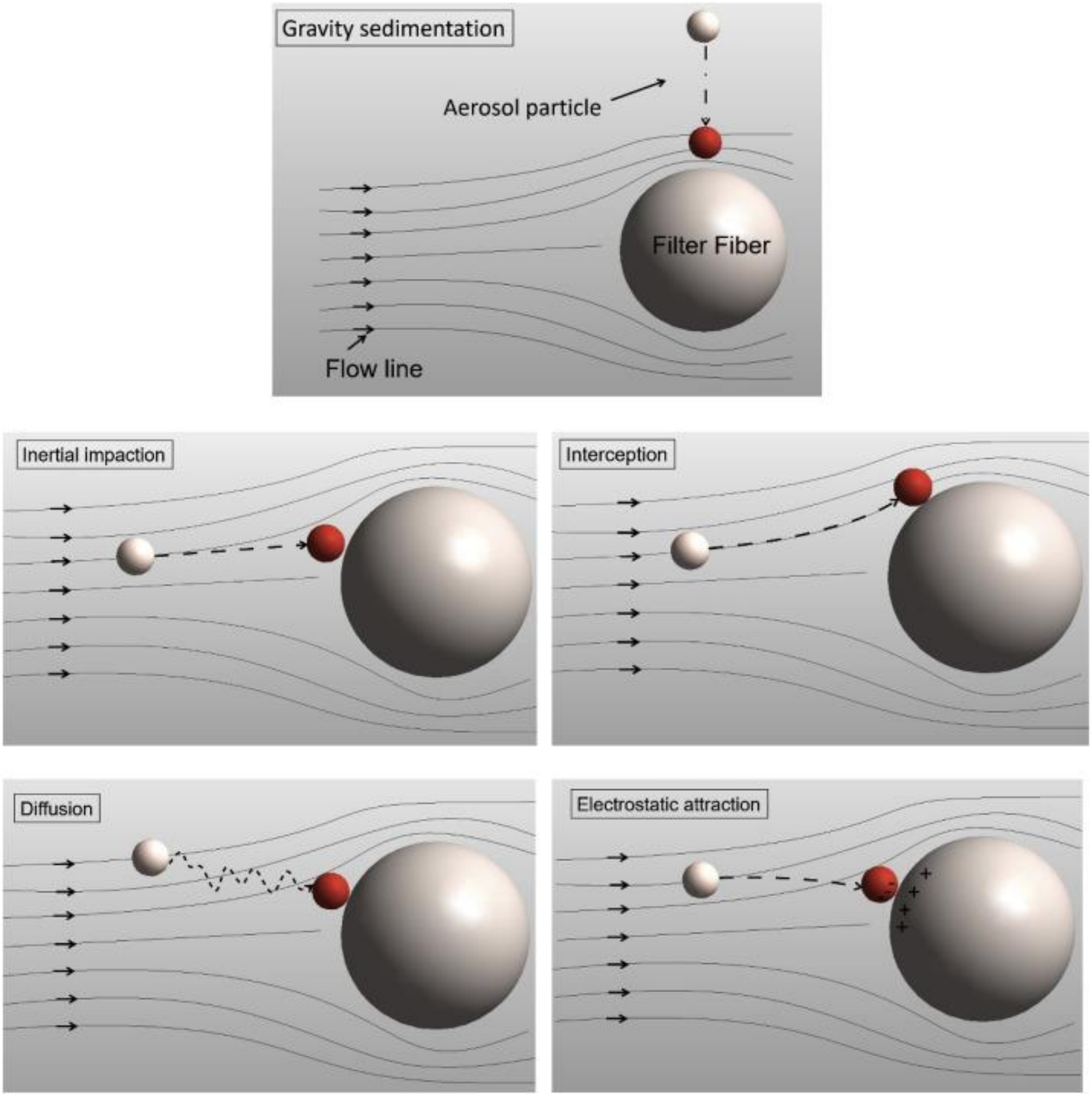


Figure 1 : Illustration of aerosol penetration mechanisms through face masks[1].

Gravity sedimentation is a critical mechanism in aerosol filtration, primarily affecting larger particles in the range of 1 µm to 10 µm[2]. This mechanism becomes significant when particles exhibit early gravitational forces or ballistic energy. Notably, for particles larger than 0.5 µm, inertia and gravity dominate the capture process, as it has been predicted that particles as small as 0.5 µm possess the highest penetrating ability[3].

Inertial impaction comes into play when particles exhibit substantial inertia, leading to changes in their movement direction within the airflow. Particles with larger sizes, increased face velocities, and higher densities exhibit greater inertia, making them more likely to be captured. These particles are unable to maneuver around respirator fibers and tend to collide with them, subsequently adhering to the fibers. Inertial impaction is most effective at capturing particles around 1 µm or larger[4]. However, it is less effective in capturing nanoparticles, where Brownian motion plays a more significant role[1].

Interception is the mechanism by which particles follow the primary airflow streamlines, allowing interaction with the filter media within a particle's width of the fiber surface. This method is effective in capturing particles up to 0.6 μm in size[4]. Unlike inertial impaction, interception is not influenced by particle velocity but becomes more pronounced as particle size decreases. A crucial distinction between interception and inertial impaction is that there is no deviation from the central streamline in interception; instead, the filter media intercepts the particles. Interception is particularly prevalent in capturing particles ranging from 100 nm to 1 μm, where diffusion by Brownian motion and mechanical interception are the dominant mechanisms[1].

Diffusion relies on the random Brownian motion of particles as they interact with the filter media, making it the most effective mechanism for capturing particles smaller than 0.2 μm[4]. The erratic motion of particles increases the likelihood of collision with fibers within a streamline that does not intercept, making diffusion crucial for capturing ultrafine particles and nanoparticles. As particle size or facial velocity decreases, diffusion becomes increasingly significant, leading to prolonged particle residence time within the filter media and a higher probability of collision. Mathematical models like Fick's first and second laws describe the mass diffusion across filter media[1].

Electrostatic attraction is a mechanism that efficiently captures particles of various sizes from the airstream. This technique utilizes electrically charged fibers or granules within the filter to draw oppositely charged particles from the airstream[5]. However, at the nanometer scale, particles can traverse the openings in the filter fiber network. This electrostatic mechanism is particularly useful at low velocities, such as those experienced during respiration through a facemask. However, the efficacy of electrostatic attraction diminishes with increasing airflow speed. Electrostatic filters, also known as electrets filters in the literature, exhibit distinctive performance characteristics compared to non-charged mechanical filters. For particles around 300 nm, mechanical filters have been described as the most penetrating, while the efficiency of electret filters decreases for particles smaller than this size[3]. Moreover, charged and uncharged particles exhibit differential penetration rates, with uncharged particles showing higher penetration for particles sized 30–40 nm[6]. It is important to note that the most penetrating particle size (MPPS) varies for different particle types at different flow rates, with decreased airflow rates resulting in an increased MPPS[1].

Mask Fabrication and Types

The creation of fibrous media for face masks relies on a range of techniques, including airlaid, wetlaid, spunbond, meltblown, electrospinning, and more. However, the production methods that truly stand out due to their ability to generate microfibers and nanofibers, essential for filtration efficiency, are meltblown and electrospinning[7]. In this section, we delve into these two fundamental techniques, exploring their core principles, critical processing parameters, and the latest developments in the field.

Meltblown is a widely used and efficient method known for its affordability and high production capacity in crafting filtration layers for masks. In the typical meltblown process, a polymer resin is melted by an extruder and transported to a die assembly, where a gear pump regulates the flow rate. The molten polymer is then extruded through small orifices at the tip of the die assembly and stretched by converging streams of hot air. Turbulent air adds to the fragmentation of the polymer stream, leading to the formation of microfibers that subsequently interlace. As these fibers fall towards the collector, they solidify, ultimately forming a self-bonded web. Notably, the design of the die assembly is a critical aspect of the meltblown process, and it has witnessed considerable development over the years. Most commercial meltblown systems use a slot design, where numerous die orifices with diameters ranging from 0.2 to 0.6 mm are arranged at specific intervals[8,9]. Polypropylene remains the most popular choice of polymer for meltblown due to its favorable attributes, including a high melt flow index, low melting point, low glass transition temperature, cost-effectiveness, and versatility in producing a wide array of products. While theoretically, almost any thermoplastic polymer can undergo the meltblown process, the practical challenges and unsatisfactory rheological behaviors of many polymers limit their suitability. The average fiber diameter produced by commercial meltblown systems typically falls within the range of 1 to 10 mm, with a typical attenuation ratio of around 100. Several key processing parameters influence fiber diameter, including air velocity, polymer throughput, melt flow index, processing temperature, orifice size, and die-to-collector distance[7].

Despite the motivation to create finer meltblown fibers for enhanced filtration efficiency, the production of submicrometer-diameter meltblown fibers has primarily remained at a laboratory scale. Some research endeavors have successfully achieved submicrometer-diameter meltblown fibers by meticulously adjusting processing parameters and die designs, resulting in reported average diameters around 300 nm[10]. However, the challenge of achieving industrial-scale production of finer fibers remains a prominent issue in the field[7].

Electrospinning, on the other hand, is a straightforward and versatile tool for fabricating nanofibers, making it an increasingly attractive choice for air filtration applications. The fundamental setup for electrospinning involves housing a polymer solution within a syringe, where a metal needle is connected to a syringe pump to control the solution's flow rate. A high voltage, typically ranging from 1 to 30 kV, is applied to a needle, which is positioned 10 to 20 cm away from a grounded collector. At the needle's tip, a droplet of the polymer solution, held in place by surface tension, becomes charged and elongated into a conical shape referred to as the Taylor cone. Once the electric field intensity reaches a critical point, the combined Coulombic force and electrostatic repulsion among surface charges overcome surface tension, resulting in the ejection of an electrified jet from the Taylor cone's tip. This jet then undergoes a whipping process[11] as the solvent evaporates, ultimately forming charged polymer fibers that are randomly deposited on the grounded collector[7].

What sets electrospinning apart from meltblown is its ability to easily produce nanofibers with diameters less than 100 nm. The process offers finer control over fiber diameter, enabling the production of exceptionally thin fibers. Key parameters that impact fiber diameter include decreasing the viscosity of the precursor solution, increasing solution conductivity, and applying a stronger electric field. However, electrospinning faces its share of challenges, such as bead formation or jet breakup into droplets, often resulting from insufficient solution viscosity, excessively high electric fields, or excessive solution feed rates[7].

Figure 2 provides a comparative analysis between meltblown and electrospinning, comparing the fabrication process, setup, and the resulting fibers. One of the primary drawbacks of electrospinning when compared to meltblown is its lower production rate and higher cost. Several factors contribute to this limitation. First, increasing the throughput by using more needles poses challenges due to deteriorating local electric fields near neighboring needles. The inter-needle distance becomes crucial for process stability and uniform fiber distribution. High-throughput production faces an additional challenge related to polymer clogging in needles, which is particularly prominent when volatile solvents are utilized. To overcome this, needleless electrospinning methods have been explored, as they can offer greater scaling-up potential. The use of volatile organic solvents in electrospinning contributes to higher production costs, with solvent costs often exceeding those of the dissolved polymer. Additionally, solvent evaporation can pose environmental and safety hazards without proper treatment or recovery. Lastly, electrospinning requires a conductive fiber collector, which can limit scalability and flexibility in fiber deposition. Efforts to address these challenges are ongoing, with continued research aiming to unlock the full potential of electrospinning for air filtration applications. As of the present moment, industrial mask production primarily relies on the meltblown method.

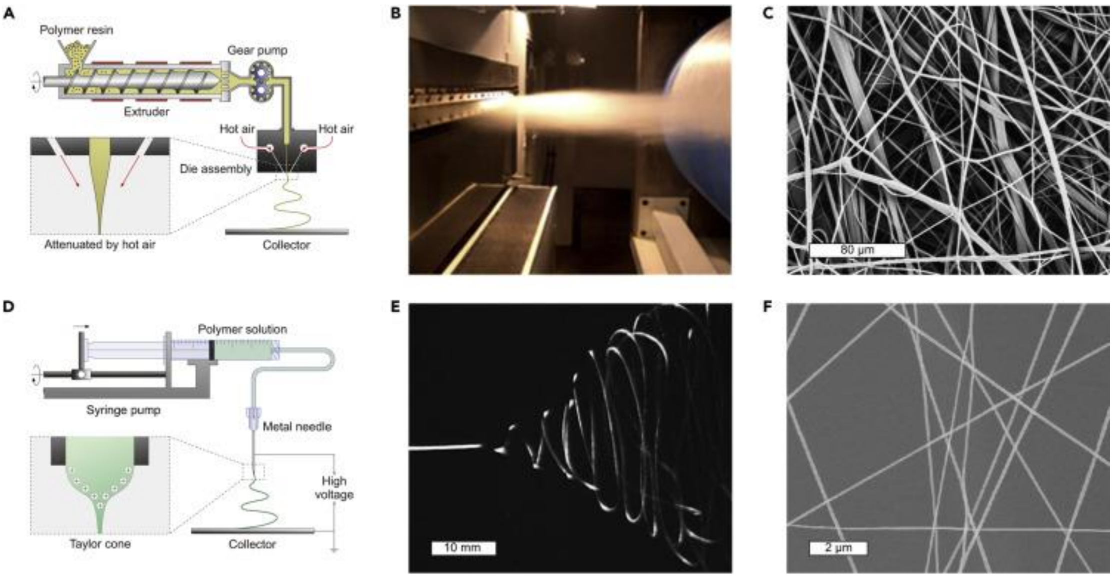


Figure 2: Fabrication of fibrous media. (A) Schematic of the meltblown process. (B) A commercial meltblown system and (C) SEM image of meltblown microfibers. (D) Schematic of the electrospinning process. (E) The whipping electrified jet during electrospinning and (F) SEM image of electrospun nanofibers[7].

A variety of masks can be found in the market. They offer different levels of protection and have specific advantages and disadvantages. Cloth masks are simple, emergency-use masks often chosen during pandemics due to the scarcity of more advanced options. However, studies show they have higher aerosol penetration rates than N95 respirators, making them less effective, especially for smaller particles. Surgical masks were initially designed to protect against infectious droplets in clinical settings, these masks offer some protection from fluid splashes and capturing respiratory droplets. They might not effectively prevent the spread of smaller respiratory particles. Filtering facepiece respirators cover the nose and mouth, filtering airborne particles like dust, infectious agents, and gases. N95 and KF94 respirators are well-known examples, with N95 masks filtering at least 95% of aerosols around 0.3 μm in size. However, their efficiency may decrease against smaller aerosols, and different N95 respirators may vary in performance depending on particle size.

The choice of mask depends on the specific scenario and the required level of protection. N95 respirators provide the highest efficiency for smaller particles, while basic cloth masks are more suitable for emergency use and surgical masks offer protection in clinical settings[1].

Filtration performance

Filtration performance is influenced by various intrinsic and extrinsic factors[7]. The thickness of a fibrous medium plays a vital role. Increasing thickness improves filtration efficiency but also raises pressure drop. Therefore, the quality factor remains relatively constant as the two factors offset each other[12]. Fiber diameter, specifically nanofibers, enhances filtration efficiency due to their increased surface area and smaller pore size but may raise air friction and pressure drop. The influence of fiber diameter on the quality factor is debated, with simulations suggesting drawbacks for particles smaller than 0.1 μm, while experimental studies show potential quality factor improvements with nanoscale fibers[13]. Packing density affects filtration, with higher density improving efficiency but potentially causing impractical pressure drops, particularly for nanofibers. These fibers are prone to mechanical fragility and clogging, leading to rapid pressure drops during use[14]. Electret filters, like N95 masks, rely on electrostatic charge to enhance filtration efficiency, and their mechanical filtration contribution can be minimal, emphasizing the importance of charge stability[15]. The impact of the fibrous medium's chemical composition on filtration performance, particularly the dipole moment of polymer repeating units, has received less attention but holds potential for better performance[16].

Extrinsic factors also play a pivotal role in filtration performance. Higher face velocity leads to lower efficiency and increased pressure drop, reducing quality factors. Pleating filter media effectively enhances quality factors by expanding the filtration area. Elevated inhalation flow rates can compromise efficiency, particularly through mask-face seal leakage. Humidity significantly impacts electret filters by leading to charge decay and reduced shelf life. Nonpolar polymers, such as polyolefins, are preferred for electret filters due to their ability to maintain charge retention. Sterilization methods are crucial for mask reuse during pandemics. Techniques like heat, ultraviolet germicidal irradiation, and hydrogen peroxide fumigation show promise for preserving filtration efficiency[7].

Jung et al.[17] evaluated the filtration efficiency and pressure drop of various mask types used by ordinary citizens and healthcare workers. The results showed that respirators exhibited the highest filtration efficiency, while general masks offered the lowest protection. Professional FFP2 masks outperformed surgical masks. Notably, some surgical masks displayed penetration values over 20%, suggesting their limited effectiveness. The study revealed that no significant differences existed between KF94 and N95 respirators in terms of penetration, but the KF94 respirator resulted in a significantly lower pressure drop. This discrepancy was attributed to variations in flow rates between protocols used by the two respirators. The absence of strict regulations for filtration efficiency and pressure drop in surgical masks was noted, emphasizing the need for guidelines to safeguard citizens from inhaling harmful substances effectively.

Antimicrobial performance

Antimicrobial face masks have emerged as a promising solution to address concerns associated with conventional disposable face masks. These concerns include the viability of pathogens on mask surfaces, the potential for fomite transmission, and the favorable conditions for microbial growth within masks. Antimicrobial face masks offer real-time protection against microorganisms and the formation of biofilms, reducing the risk of secondary infections in users. Various types of antimicrobial agents (AMA) have been developed and incorporated into face masks (**Figure 3**). These agents include metals (e.g., silver, copper, zinc oxide), quaternary ammonium or phosphonium compounds, antimicrobial peptides, natural compounds, and more. These AMAs can effectively deactivate or kill microorganisms, preventing biofilm formation[18].

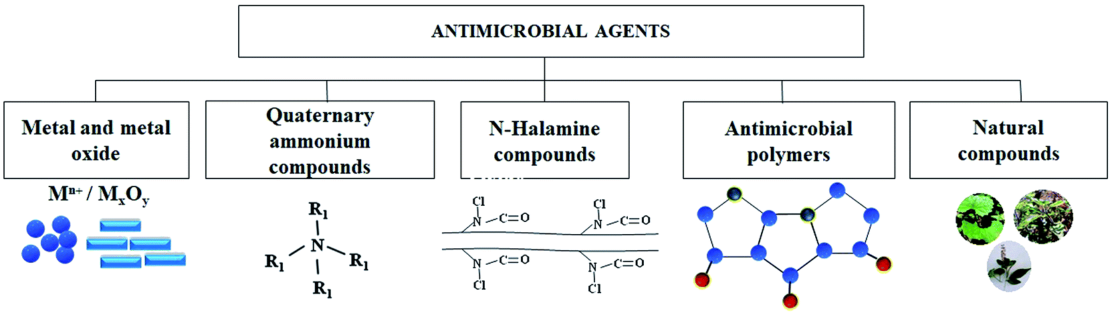


Figure 3: Diverse antimicrobial agents are employed in the production of face masks[18].

Metals like silver, copper, zinc oxide, and others have been used as antimicrobial agents. Silver, especially in nano-forms, is known for its antibacterial, antiviral, and antifungal properties. Copper, copper nanoparticles, copper oxide, and copper iodide have been effective against various viruses. These metals interact with microorganisms through complex processes, including penetration, thiol group interactions, formation of free radicals, and disruption of microbial signal transduction pathways. Combinations of these metals have shown complete inactivation of microorganisms in shorter contact times. Antimicrobial polymers can be bio-passive or bio-active. Bio-passive polymers repel bacterial adhesion, while bio-active polymers are capable of killing microorganisms on the surface. These polymers can be functionalized with various bio-active agents, including metals, metal oxides, N-halamines, quaternary ammonium or phosphonium compounds, antimicrobial peptides, and antibiotics[18]. Various methods, including dip coating and spray coating, can be employed to attach antimicrobial agents to mask surfaces. These coatings provide long-term antimicrobial protection. For example, a carboxylic-functionalized surface treatment using surfactants was found to improve hydrophilicity and serve as a reaction site for attaching silver nanoparticles. Such coatings can effectively inhibit the growth of bacteria and viruses. Combining different antimicrobial agents on mask surfaces has shown enhanced antimicrobial effects. For example, face masks treated with a combination of citric acid and metals such as copper and zinc ions exhibited high reductions in bacterial and viral titers. These combinations reduce the chances of microbial resistance[18].

In conclusion, antimicrobial face masks provide a solution to the issues associated with conventional disposable masks. They offer real-time protection against microorganisms, reducing the risk of secondary infections and the generation of hazardous waste. Different antimicrobial agents, including metals, metal oxides, and antimicrobial polymers, are used to impart antimicrobial properties to these masks. Combining these agents can further enhance their efficacy, making antimicrobial face masks a promising solution for infection control and waste reduction[18].

New mask technologies

New mask technologies have been developed to address the issues of current face masks. For example, electrostatic charge on N95 or surgical masks decay over time, especially in humid conditions due to moisture from exhaled breath. This decay can cause a decline in the electrostatic adsorption efficacy[19]. To tackle this problem and extend mask protection, various methods have been explored.

In one case, researchers applied a continuous high-voltage charge (20 kV) to a polyethylene terephthalate filter coated with polydopamine, maintaining an average capture efficiency of 99.48% for 0.3-µm particles over 30 days[20]. Another approach utilized an ionic liquid polymer-coated melamine formaldehyde sponge, achieving a removal efficiency of 99.59% for PM2.5 with a low voltage source (3 V) and demonstrated stability during a 21-day test[21]. They also harnessed the triboelectric effect, a result of contact electrification, to create external energy harvesters. For example, a freestanding sliding triboelectric nanogenerator charged a nano/microfibrous hybrid air filter, ensuring a consistent 94% capture efficiency for 0.3-µm particles over 48 hours[22]. Furthermore, a self-powered face mask, driven by the triboelectric effect, maintained an efficiency of 86.9% for 0.3 µm particles after 240 minutes of filtration, remaining stable even after 30 days of storage[23]. Additionally, a multi-layer film integrated into a face mask showcased the potential of hybrid piezoelectric and triboelectric energy harvesting for breath-activated self-powered masks[24]. These innovations offer ways to extend mask protection effectively.

In addition, new mask technologies include biodegradable masks and washable masks aimed at reducing the environmental burden[25-27]. These masks reduce the use of disposable masks, contributing to sustainability. Furthermore, there are health-monitoring masks that can track wearers' physiological indicators like breathing[28-30], offering comprehensive health protection. There are also multifunctional masks that prioritize aesthetics, sun protection, and other factors in addition to functionality, providing more choices and convenience.

Survey study on the use and efficacy of face masks

Objectives

This survey is committed to uncovering the habits of people using face masks and their perceptions of the efficacy of face masks via a series of questionnaire surveys conducted in China and Hong Kong, China. This survey also targets unveiling the public understanding of the environmental pollution caused by a large number of discarded face masks under the epidemic trend that is still prevalent worldwide. Furthermore, this survey aims to know public acceptance and views on the future development of new mask technologies.

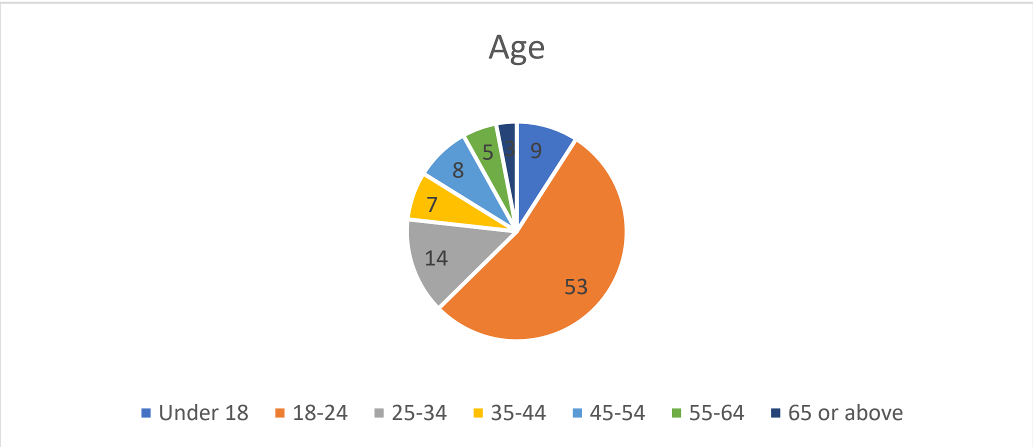
Methodology

This social survey adopts the questionnaire survey method. The questionnaire contains 6 parts and 74 questions. Totally 934 valid responses were collected online. The first part is about the use of face masks and public perceptions of mask protection efficacy, and the second part surveys people's mask-wearing behaviors and corresponding improvement measures. The third part concerns the environmental challenges raised by discarded face masks and public knowledge of new technology masks, and the fourth part surveys the government's efforts in the disposal of discarded masks. The last two parts investigate new mask technologies, including reusable and self-charging face masks. The original questionnaire can be found in Appendix A.

Results and discussion

#Part 1: Use of Face Masks and Public Perceptions of Mask Protection Efficacy

This questionnaire consists of three parts with 14 questions. The first part is personal information. The second and third parts are about the use and efficacy of masks in Hong Kong, China and other regions. 100 valid responses were collected within 2 weeks. Most respondents (53.5%) were 18–24 years old. Under 18, 25–34, and 35–44 years old account for 9.1%, 14.1%, and 7.1%, respectively. Among the respondents, females account for 52% and males for 48%.



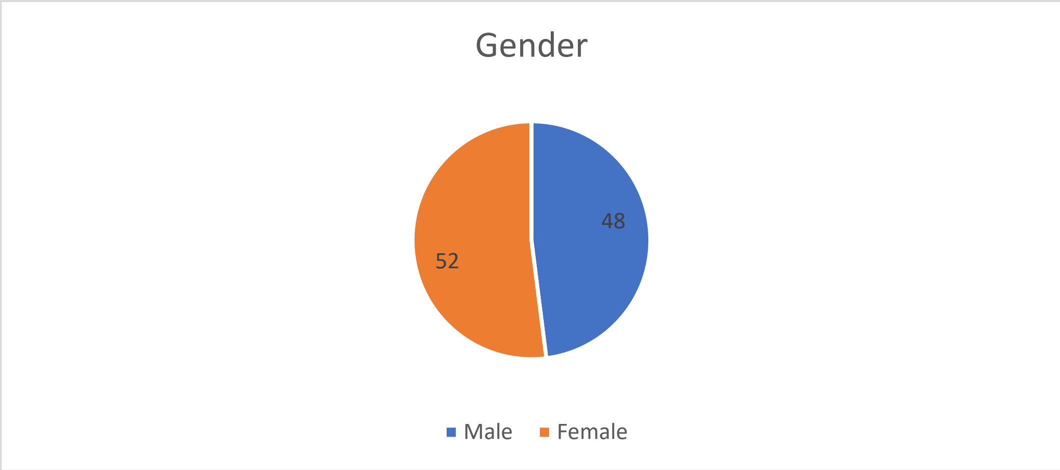


Figure 4: Personal information of the respondents.

In daily life before the pandemic outbreak in 2019, people wore face masks on different occasions. Typical types of masks include surgical, dust, and activated charcoal masks, depending on their usage. A surgical mask is a disposable, loose-fitting gear that forms a physical barrier to isolate the user's lips and nose from the potentially harmful pollutants in the immediate surroundings. It can filter bacteria and viruses that are larger than 0.5 microns to prevent droplet splatter and keep the wearer's saliva and respiratory secretions from being exposed to surroundings. Surgical masks have been widely used among healthcare workers and patients. Dust masks (e.g., pitta masks and cotton masks) are reusable and washable gear that can filter large particles like dust and capture plant pollens ranging from 5 to 100 microns in size. Therefore, it is suitable against smog and helps keep warm in winter. The activated charcoal mask is a filtration technology that employs a bed of activated carbon to adsorb contaminants from a fluid that can effectively filter volatile organic compounds (VOCs) and odors, such as ethanol and acetone benzene. Activated charcoal masks are widely used in motorcycle riding, household cleaning, and industrial gas processing, such as siloxanes and hydrogen sulfide removal from biogas.

During the difficult times of COVID-19, however, the viruses are more contagious and easier to transmit through air. Dust masks and activated charcoal masks are not enough to block the virus. Masks that can provide better protection and filter capability are in much need. Our questionnaire results show that except for the surgical mask, which is the most commonly used type of masks during the COVID-19 pandemic, accounting for 57% of the statistics. There are more and more people who tend to wear respirators. 27% of people choose respirators (e.g., N95, KN95, KF94). This is because people's epidemic prevention awareness has increased significantly. They tend to choose mask with a higher protection level to prevent the SARS-Cov-2 variants. Respirators are respiratory protective gear with a very close facial fit and efficient airborne particle filtration. The edge of a respirator is curved to establish a seal around the nose and mouth. Respirators are designed mainly for construction and other industrial jobs where employees are exposed to dust and tiny particles. Nowadays, respirators are used to filter airborne viruses and bacteria from the surrounding environment.

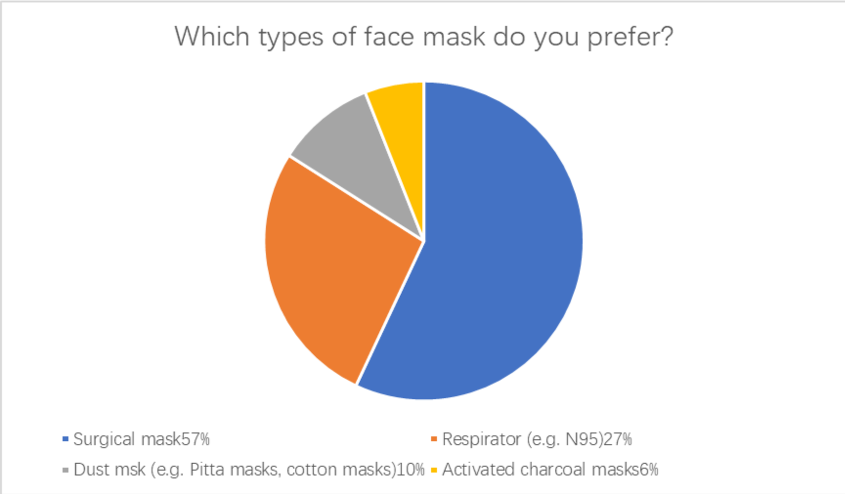


Figure 5: Statistics on used types of masks.

In the question "On what occasion do you wear a mask", 81% chose to wear a mask in any public place, 44% in any outdoor environment, 40% in indoor public places, and 38% in outdoor public places where social distance cannot be maintained. This indicates that the rate of mask-wearing in public places is still very high. In addition, 36% of the respondents said they would keep wearing masks even if it is not mandatory to wear a mask, while 38% of them refused to wear face masks. The difference between the two sides is not significant, so it shows that people are still indecisive about whether they should wear a mask or not after the break out of COVID-19. There are some places and occasions are suggested to wear a mask at all times. For example, crowded and poorly ventilated places, medical places, and places near people with respiratory infection symptoms.

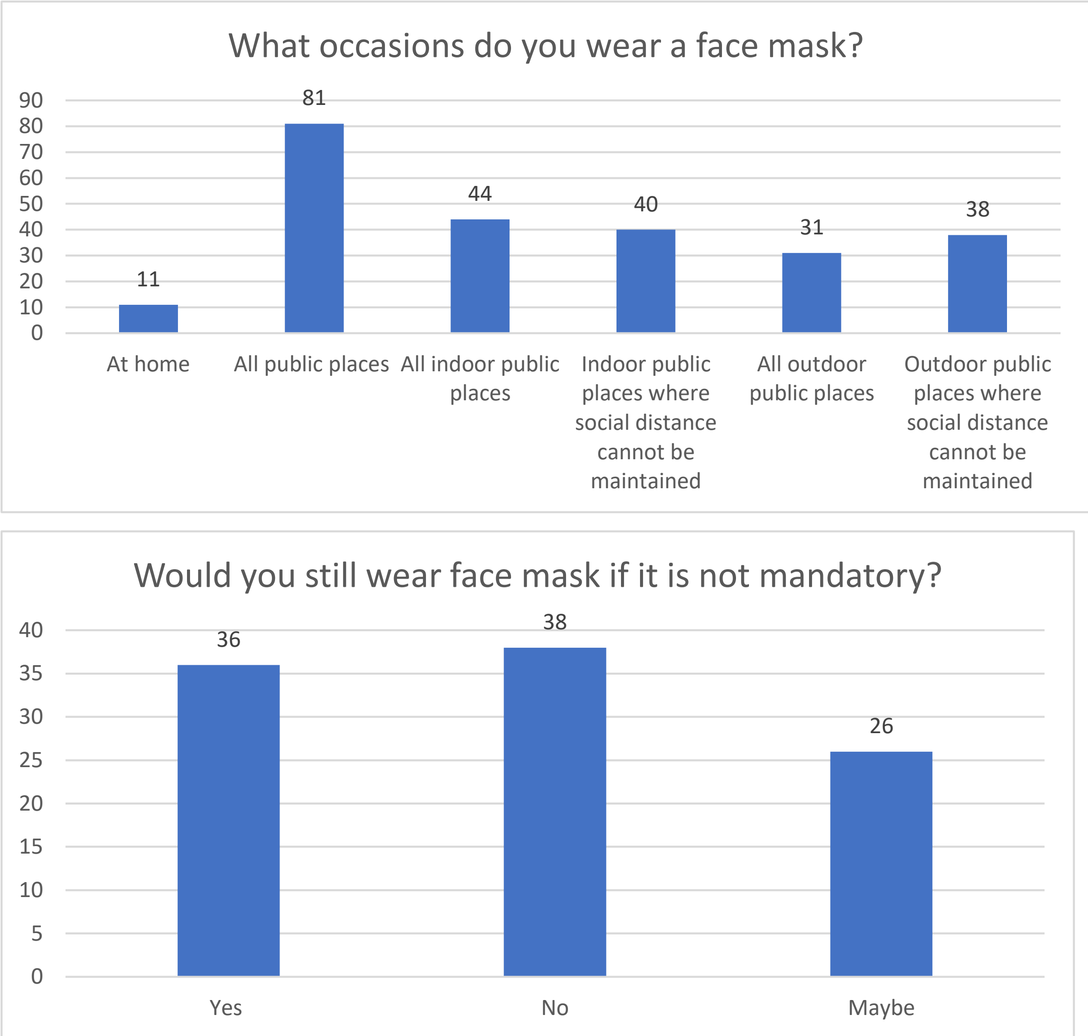
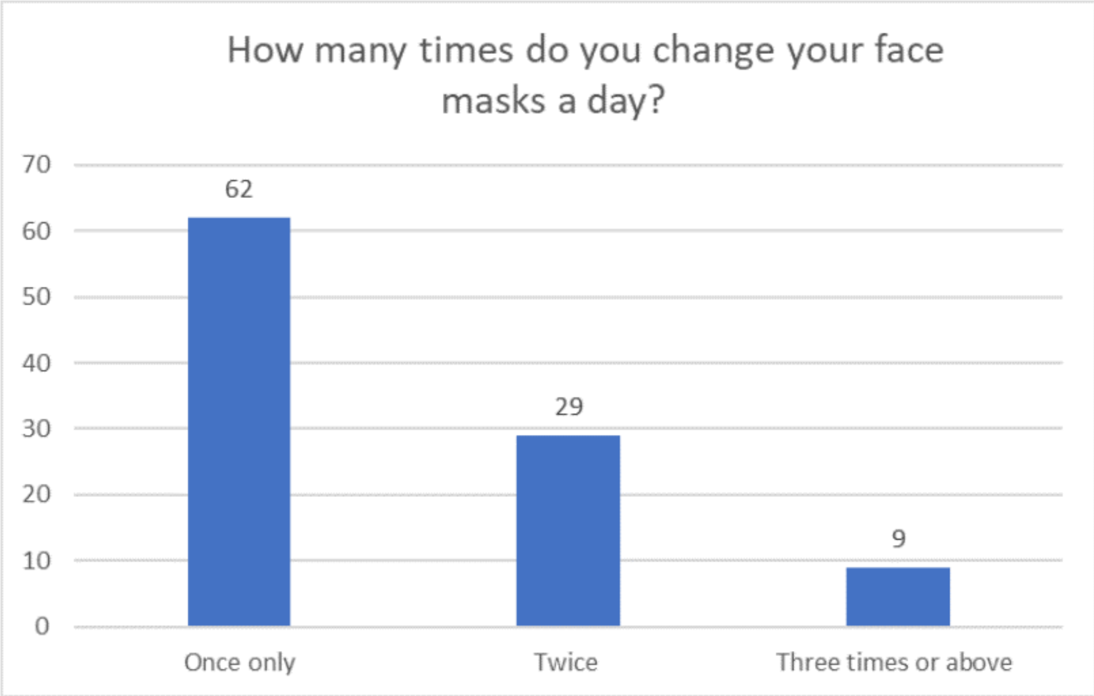


Figure 6: Use behavior of the face masks.

Regarding the mask replacement frequency, all respondents replace masks at least once a day. Specifically, 62% of people change masks once a day, 29% change twice a day, and the remaining 9% change three times a day. This result reflects that people are used to wearing a mask in their daily life, and the epidemic prevention consciousness of people during the pandemic is generally high. However, according to the WHO, we should always replace a new mask once the old one has been wetted or damaged[31]. And it is recommended to replace the mask every 4 hours[32]. If we extend the time to a week, 16% of people claimed that they had used less than three masks in the past seven days, and 27% used masks ranging from 4 to 6. The most common response is that 30% of people used masks ranging from 7 to 10, which is consistent with the daily replacement frequency shown in the last question. Besides, 17% used masks ranging from 11 to 14, and 10% used masks more than 15.



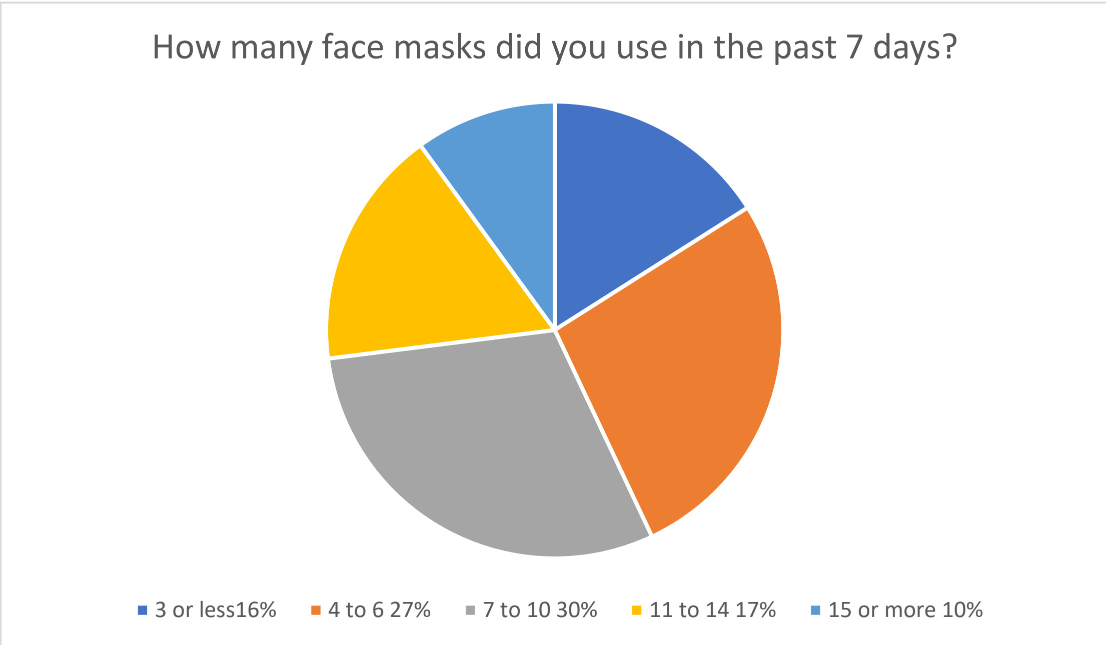


Figure 7: Replacement frequency of masks.

We also surveyed what people care more about when wearing a face mask. As we can see from the results, only 50 and 36 responders care if the mask can cover both mouth and nose and if there are proper gaps between the face and mask, and even 16 responders do not care about any of those conditions. This result reflects that the correct usage of face masks is still lacking for many respondents. People may wear face masks with loose fitment, which will not filter the air effectively and cause low filtration efficiency.

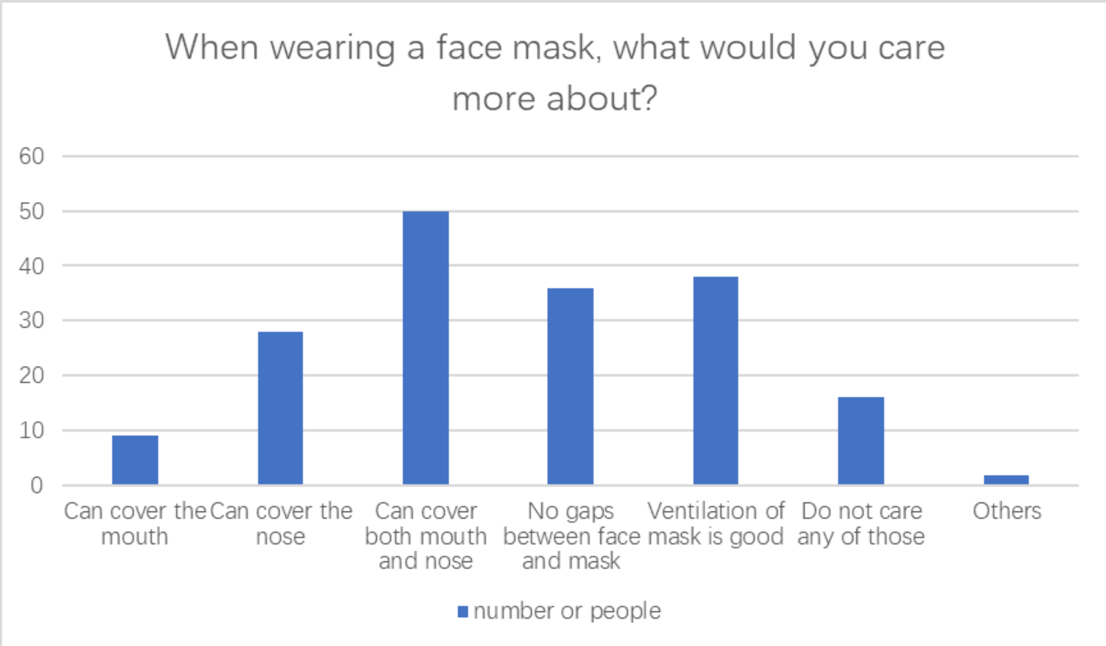


Figure 8: Concerns when wearing a face mask.

The overall impression of the protective efficacy of a mask is negative. 50% of respondents (35% disagree and 15% strongly disagree) did not consider that wearing a mask can stop viruses from spreading. This could be primarily due to recent events of soaring infected numbers leaving a negative impression of the protective efficacy of a mask.

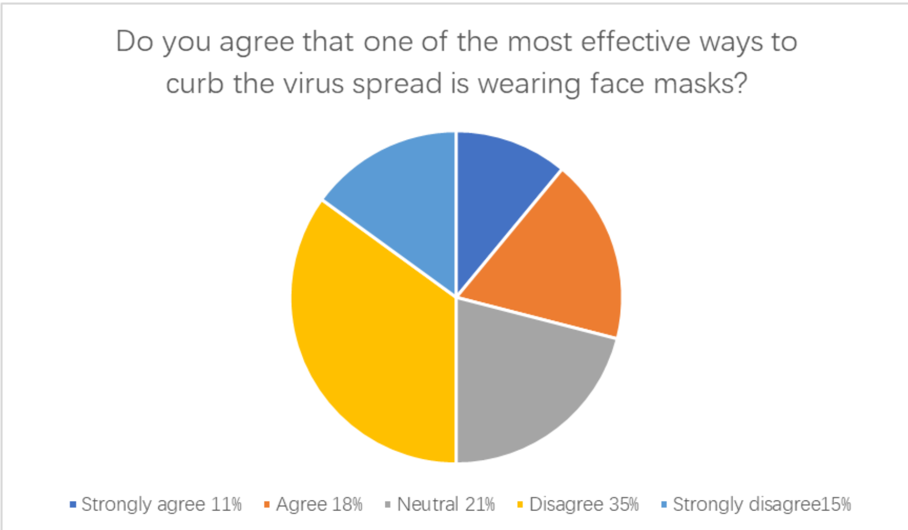


Figure 9: Confidence in masks to curb the virus spread.

Public understanding of the filtration principle of masks is important. All the four types of masks investigated in this survey can filter dust and large particles. Furthermore, the surgical mask and respirators can effectively filter bacteria or viruses in the airstream, whereas the dust masks and activated charcoal masks perform poorly or even are incapable of preventing the transmission of bacteria and viruses. The survey results indicate that most of the respondents are very familiar or familiar with the protective mechanism of masks, accounting for 14% and 24%, respectively. 33% have average knowledge, and 29% are unfamiliar or have no idea about the efficacy of protection. This shows that around 71% of respondents have basic knowledge about the mask protective mechanism and will opt for face masks with better filtering capability.

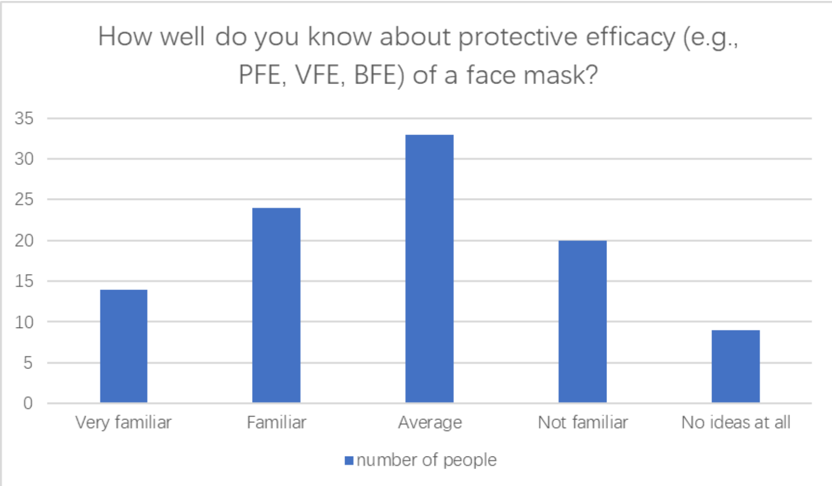


Figure 10: Knowledge level on the protective efficacy of a face mask.

For the specific protection mechanism of the face masks, 38% of responders are unfamiliar or have no ideas at all, and only 25% are familiar or very familiar with the filtration mechanisms. This shows that most people only have an insufficient understanding of the factors that affect a mask's efficacy. Relevant governments and communities should publicize such knowledge to residents so that people can have a clear understanding of the protective efficacy of masks.

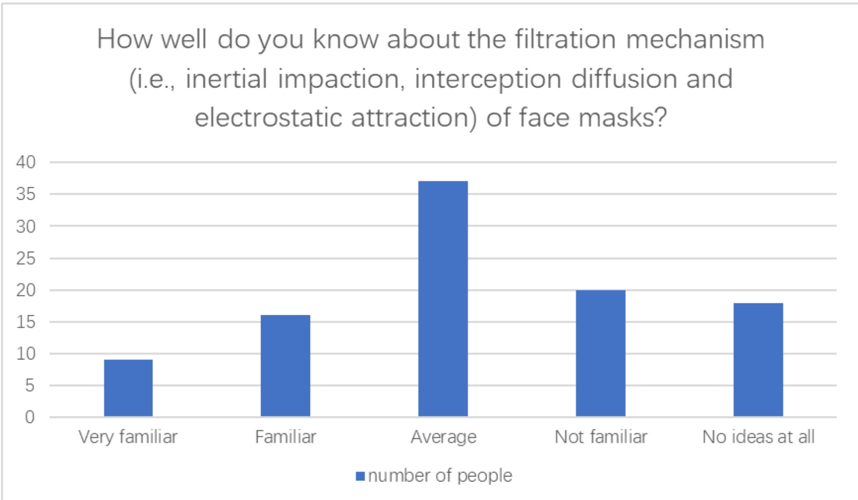


Figure 11: Filtration mechanisms of the face masks.

Even though wearing a mask daily, 31% of responders have been infected with COVID-19. It could be even higher as we are not counting possible infected cases for respondents that are not sure whether they were infected or not. This result reflects that a mask is not as protective as expected because of improper wearing or inevitable exposure, for example, when dining out.

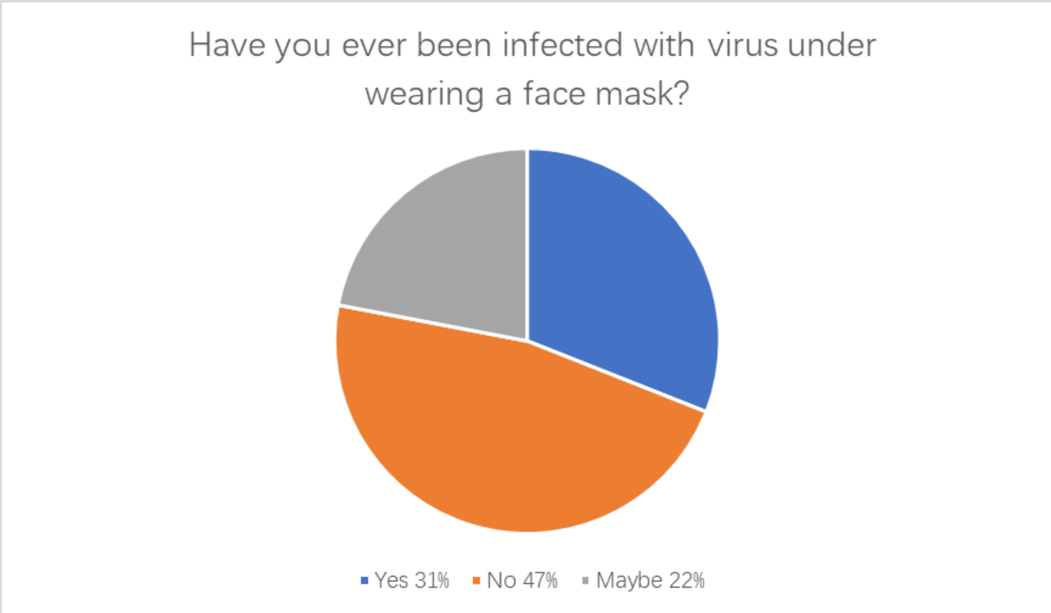


Figure 12: Infection cases under wearing a face mask.

#Part 2: Mask Wearing Behaviors and Improvement Measures

All the face masks (including respirators and surgical masks) cannot 100% prevent virus infection, but wearing a respirator or a surgical mask higher than the medical grade is one of the effective ways to prevent the spread of the virus. However, prolonged wearing of traditional masks leads to some problems of wearing experience. Some people leave their noses exposed to the air, which is no different from not wearing a mask. More importantly, many people do not store their masks properly after taking them off and instead allow the inner layer of the mask to become contaminated with bacteria. The next time they put it on, they breathe dust, viruses, and bacteria into their bodies. Therefore, it is important to wear the mask correctly in order for it to be effective. In this section, we focused on investigating the mask-wearing experience and measures to improve the face mask in terms of protective efficacy and environment-friendly. We collected 265 valid questionnaires in total, of which 50.94% are male, 49.06% are female, and 36.98% of the respondents were between 22–25 years old, 32.45% were between 25–30 years old, and 23.02% were over 30 years old.

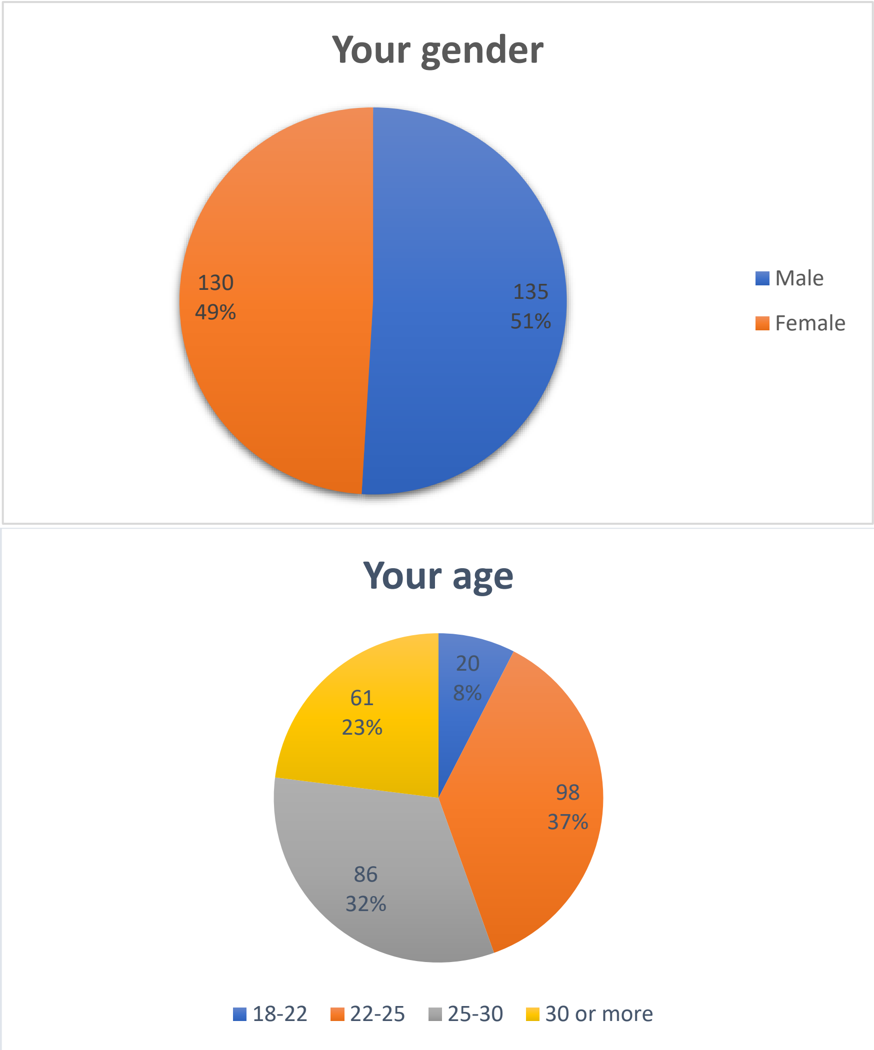


Figure 13: Personal information of the respondents.

Most respondents visit public places 3–4 times a week (55.09%), followed by almost every day (25.28%), showing that the frequency of visiting public places is generally high. Most respondents change masks 2 and 3 times a day (32.45% and 31.7%, respectively), followed by once a day (26.04%). The lowest number of respondents change 4 or more masks daily (9.81%). 36.98% of respondents change masks every 4 hours, 34.34% change their masks when the breathing resistance becomes greater, 21.89% change their masks every 8 hours, and the remaining 6.79% change their masks according to the density of people in their areas.

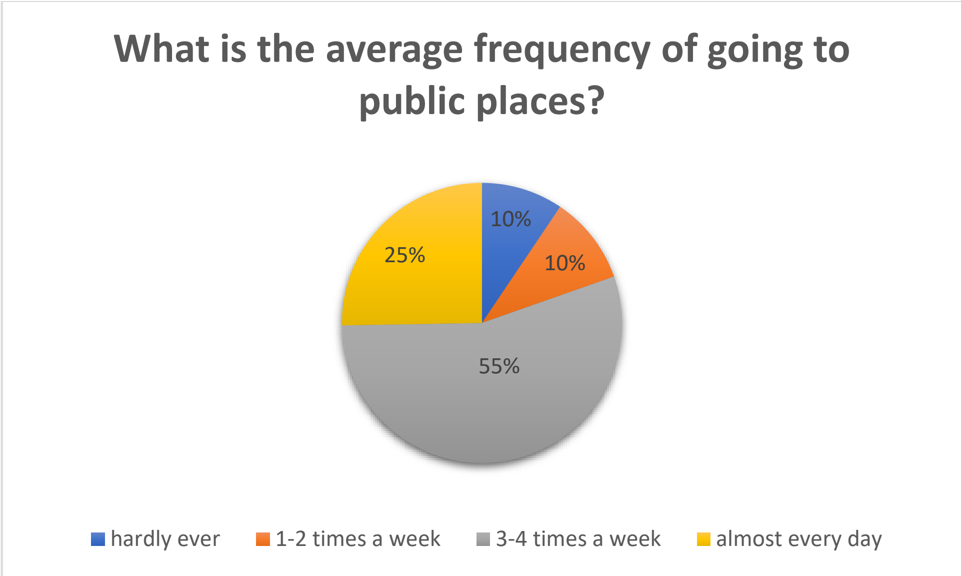


Figure 14: The frequency that respondents go to public places.

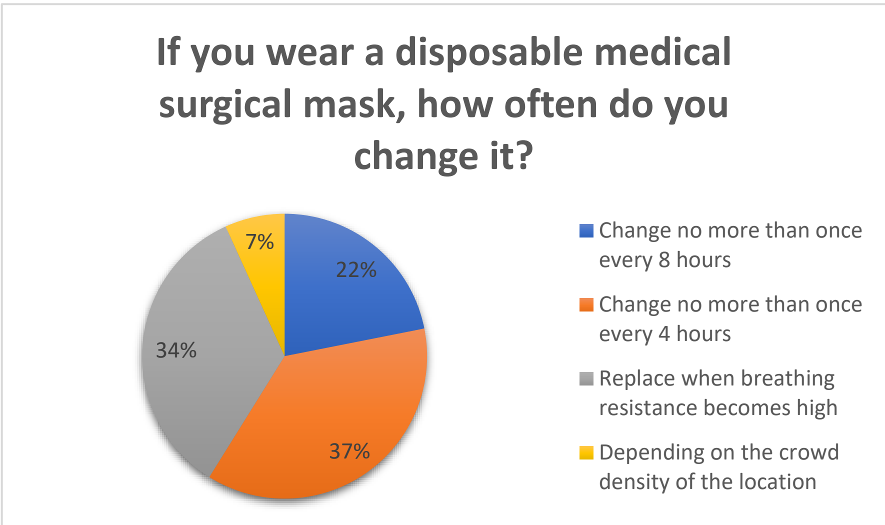


Figure 15: The frequency that respondents change their masks.

The majority of people (over 80%) are affected by the vapor they exhale when talking or exercising when using a mask. Medical surgical masks and N95 respirators are the most popular types of masks used for daily protection during the epidemic.

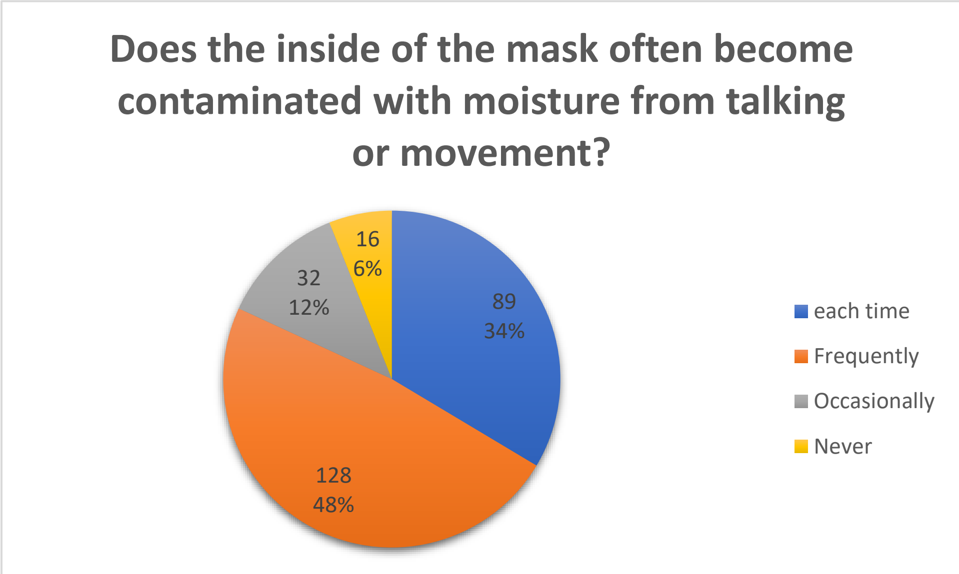


Figure 16: How often the inside of the mask become wetting.

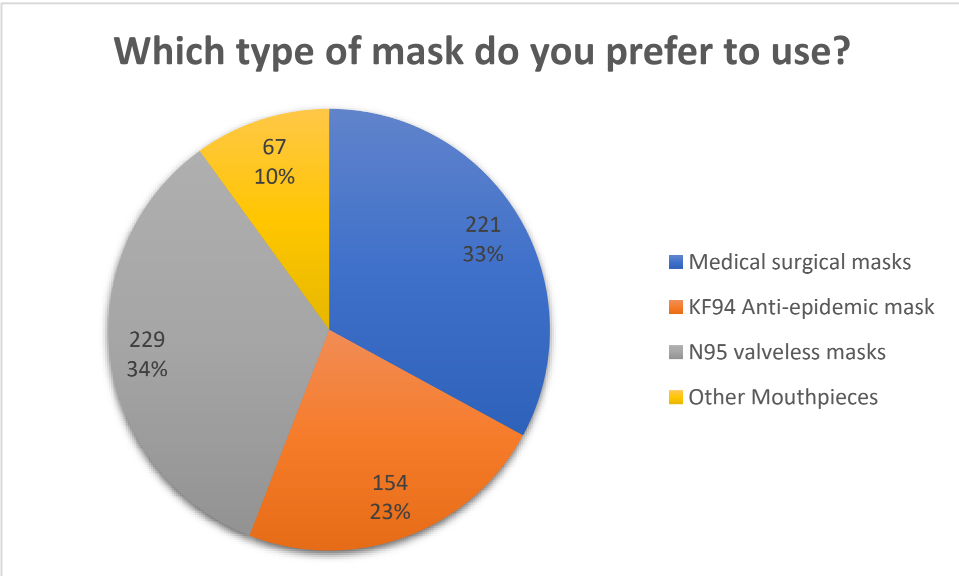
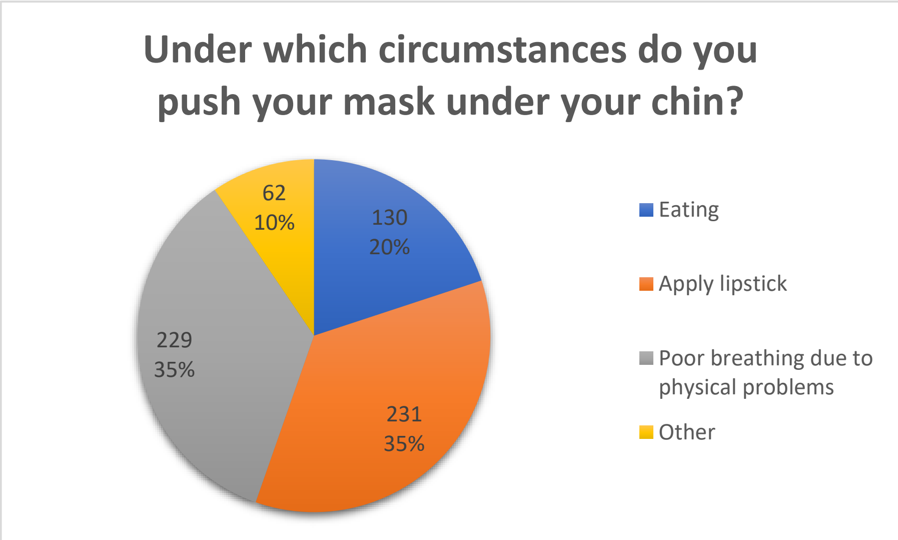


Figure 17: People's preference on types of masks.

People temporarily push their masks up to their chin when feel that it is difficult to breathe, or for convenience when applying lipstick and eating. Half of the respondents said they do not wash their hands before putting on or taking off their masks. Respondents were asked if they would touch the outside of the mask after removing it and, happily, over 70% of them have a good sense of self-protection in this regard. Even if people would touch the outside of the mask, they would immediately disinfect hands with alcohol to eliminate the potential for infection. Herein, we raise several suggestions for better protection efficacy of a mask. First of all, tighten the straps holding the mask in place so that it fits snugly over the face and covers the mouth, nose and chin completely. Second, avoid frequent touching of the mask after it has been worn to avoid reducing the protective effect; if you must touch the mask, wash your hands thoroughly before and afterwards. Third, when not being worn, masks should be folded into a clean paper bag and folded inwards against the nose and mouth, not tucked into a pocket or hung around the neck.



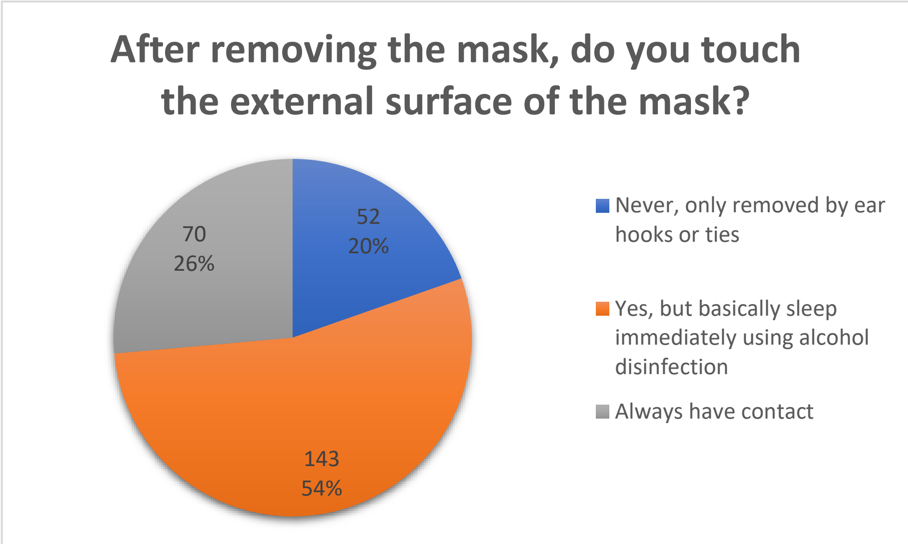
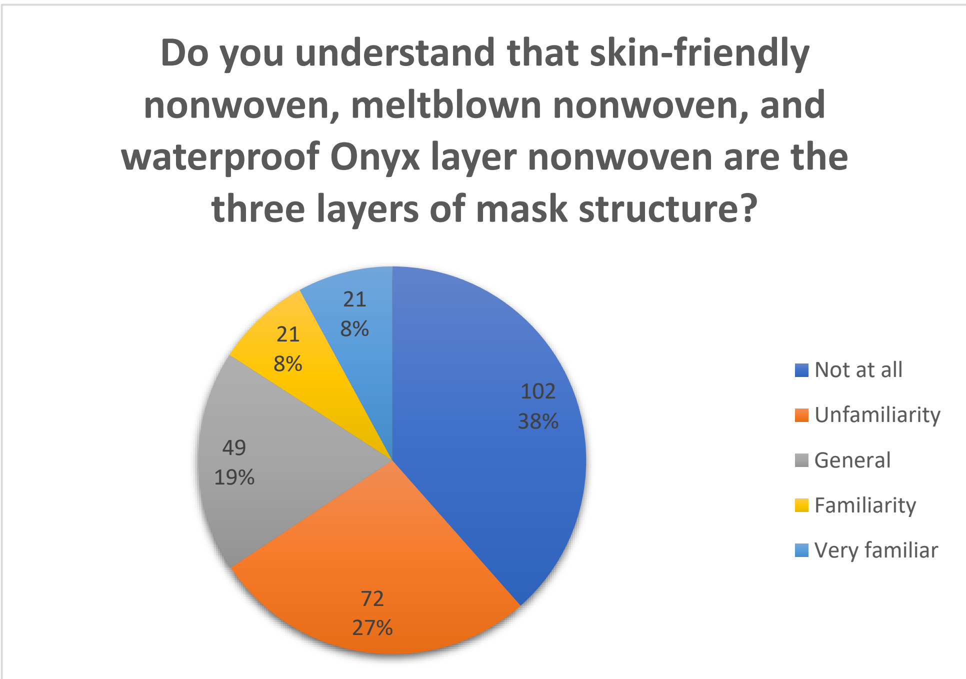
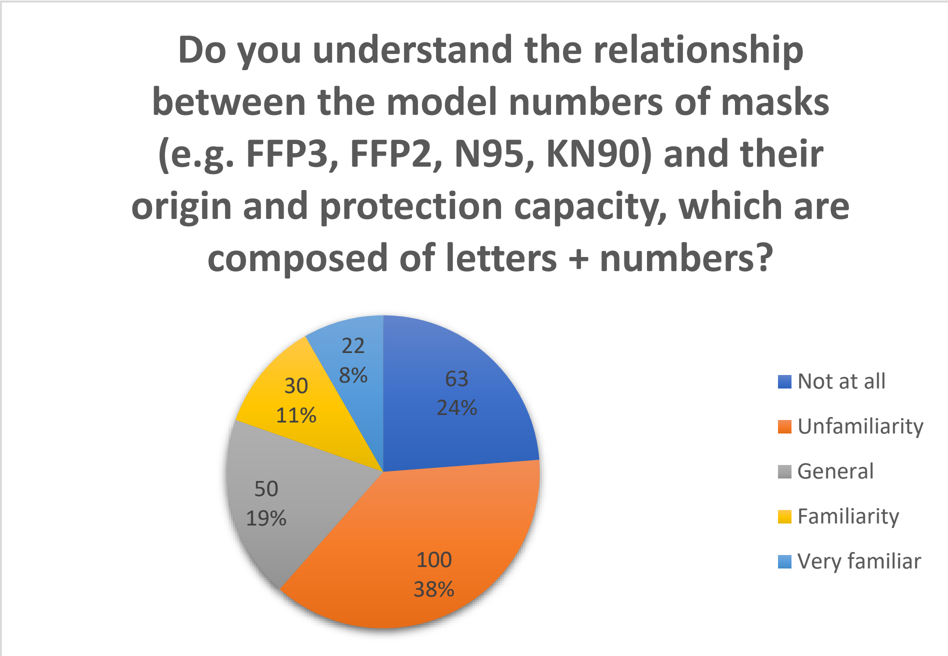
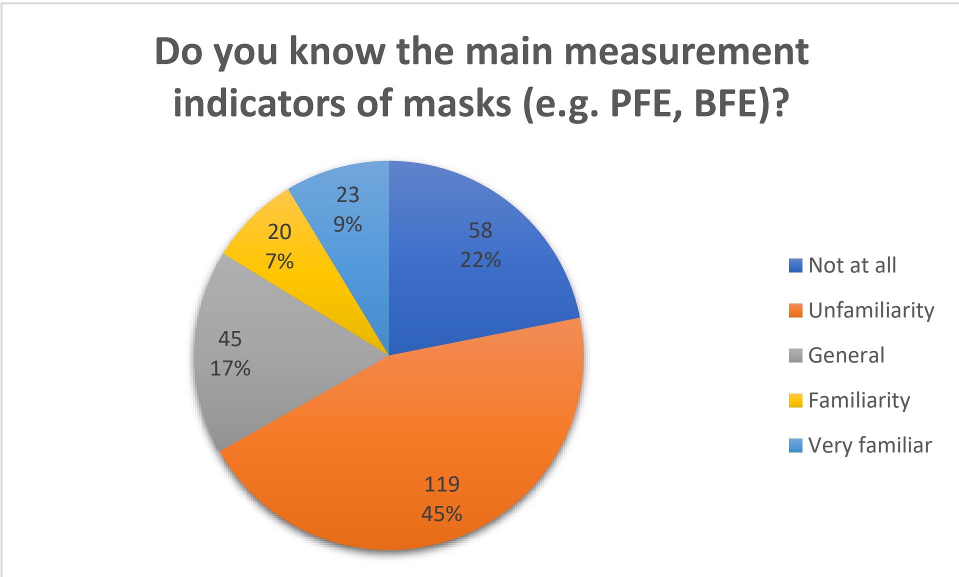


Figure 18: Mask wearing behaviors of the respondents.

The next part of the questionnaire is about the understanding of scientific knowledge of masks. Nearly 70% of the respondents are not familiar with the techniques and principles of face masks. It is not difficult to see from the results that the young people's understanding of face masks still needs to be improved. 38.49% of respondents are completely unaware of the three-layer structure of a mask, while less than 8% are very familiar with it. More than 60% of the respondents are unfamiliar with the representative relationship between mask type, origin, and protective ability. Less than 20% of respondents are familiar with the main indicators of masks and the effect of electrostatic adsorption on a mask's efficacy. About 68% of respondents are unfamiliar with or do not know the mask reuse technology.




Do you understand the relationship between the model numbers of masks (e.g. FFP3, FFP2, N95, KN90) and their origin and protection capacity, which are composed of letters + numbers?
22
8%
63
24%
30
11%
50
19%
100
38%
Not at all
Unfamiliarity
General
Familiarity
Very familiar


Do you know the main measurement indicators of masks (e.g. PFE, BFE)?
23
9%
58
22%
20
7%
45
17%
119
45%
Not at all
Unfamiliarity
General
Familiarity
Very familiar

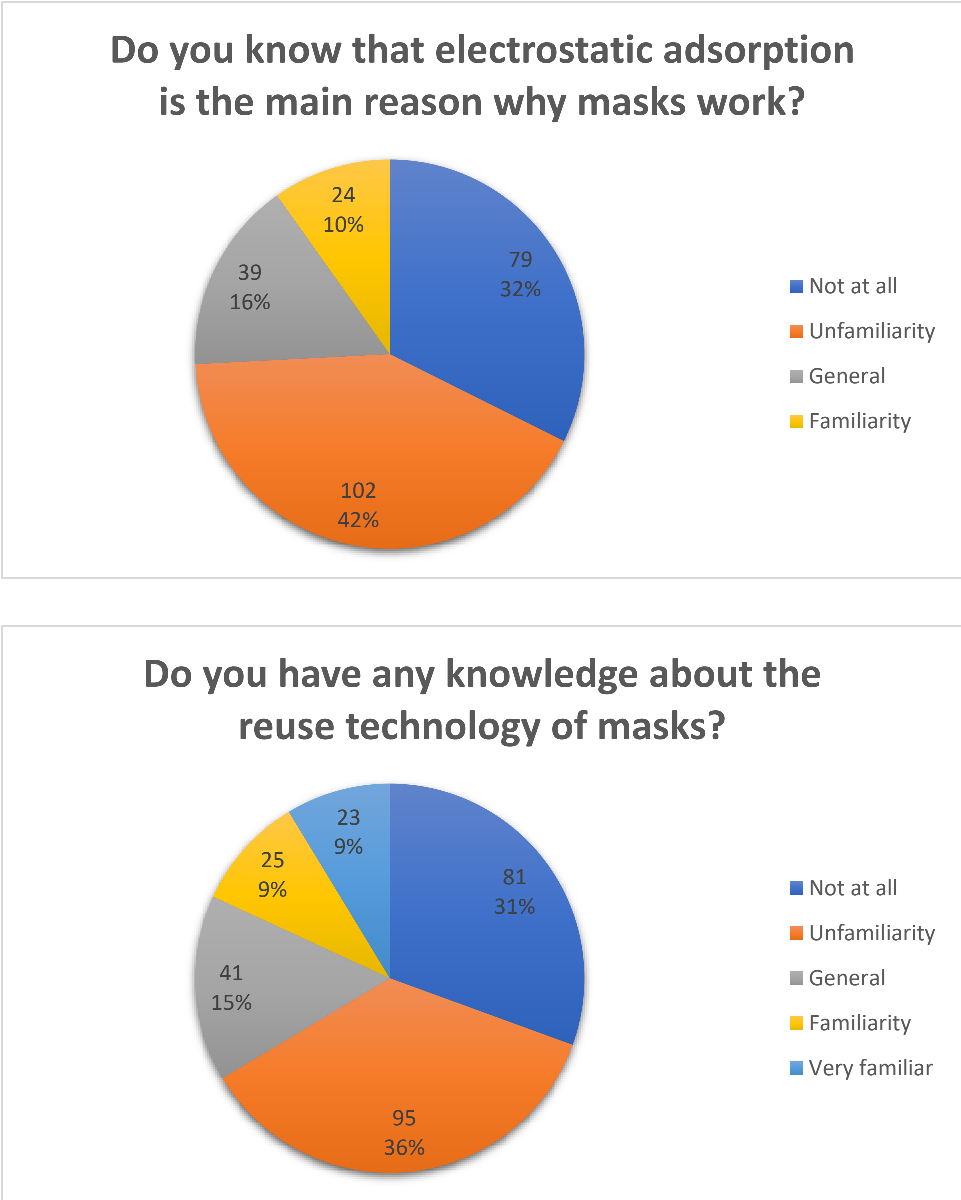


Figure 19: Public knowledge on mask indicators and new technologies.

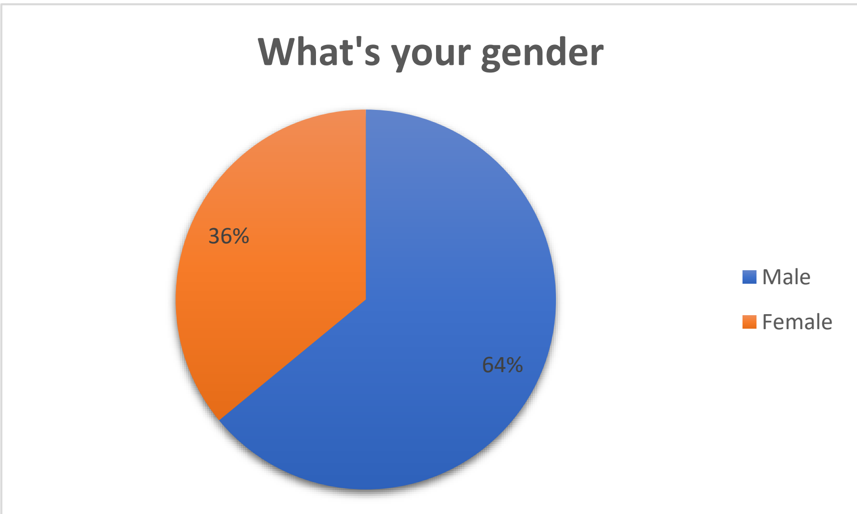
Understanding the scientific knowledge of masks is conducive to correctly using masks. However, from the investigation results, we can see that 70% of people have insufficient understanding of the structure, principle, index parameters, and evaluation system of masks and how to reuse masks to effectively improve the utilization of resources.

#Part 3: Environmental Challenges from Discarded Face Masks and Public Knowledge on New Technology Masks

With the normalization of the epidemic, environmental challenges from the discarded face masks have been significantly raised. Since the pandemic's start, the mask waste generation has been estimated to be 206 tons a day in Wuhan[33], where the COVID-19 virus was first found. In the same study, it was discovered that the number of masks used in 49 economies was approximately over 2 billion daily. In particular, China alone generates usage of 980 million pieces of masks a day, leading the number worldwide. Accordingly, due to the dramatic increase in mask usage, medical waste generation faces a sharp growth. It has been found that the total medical waste in Asia is around 16,659.48 tons/day since the outbreak, led by India with 6,491.49 tons/day[34].

Because of the increased number of discarded face masks, the world faces an environmental crisis. The used facial masks heavily pollute the marine system. These pollutants exist primarily in plastic waste (plastics) and nutrient enrichment (eutrophication), which lead to some of the most significant aquatic transformations: changing the physical, chemical, and biological characteristics of coastal and ocean zones and threatening marine diversity. Another region that is polluted heavily is the soil medium. According to the previous study[34], the leading cause of COVID-19 in soil pollution is the increasing accumulation of solid waste. Most solid wastes are caused by landfills and incineration, which release toxins and microplastic particles into the earth. In addition, the untreated used masks would not completely naturally degrade for 30 years. In this background, many masks made by new technologies have entered the public eye.

In this section, we created a questionnaire titled "Teenagers' perceptions of new technology masks" focusing on teenagers aged 18–34 from People's Republic of China and Hong Kong, China. The questionnaire surveyed the types of masks they are used to wearing, the number of masks they have worn recently, their considerations in choosing masks, and their perceptions of new technology masks. A total of 139 valid responses were collected. Among the respondents, men account for 64.03% and women for 35.97%.



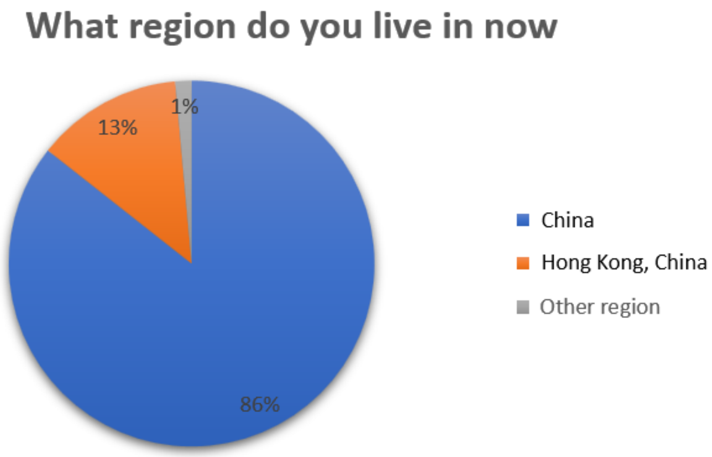
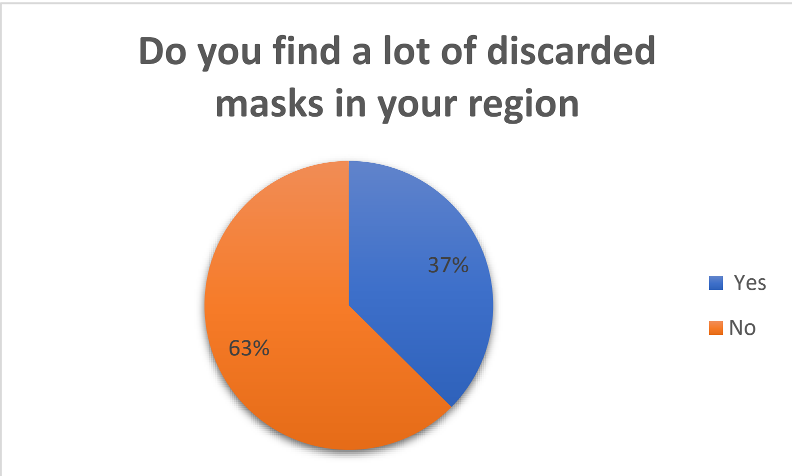


Figure 20: Personal information of the respondents.

According to the responses, 37.41% claimed that they had found many discarded masks in the place where they live. Also, they can recognize that used masks belong to the category of medical waste, which is harmful to the environment. At the same time, 56.83% felt that a large number of discarded masks caused waste, and 43.17% did not think so. So there is a large room for people to improve their environmental protection awareness. Since people need to replace masks in time for the needs of epidemic prevention and control, nearly half of people believe that regular replacement of masks will not pollute the environment. In addition, 56.83% of responders had considered the shortcomings of traditional masks, which is good news for developing environment-friendly mask technologies.



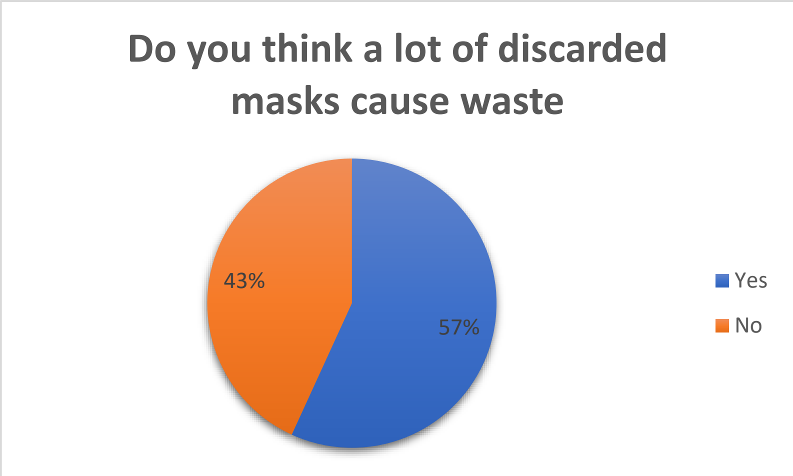


Figure 21: Disposal of face masks and the waste caused.

Regarding the face masks using new technologies (mainly referring to the green category, such as biodegradable and reusable masks), most people (71.94% of the total) have not learned about new technology masks. Out of fear of new things, people are worried that new technology masks cannot protect themselves. Therefore, even if people know about new technology masks, 81.29% of the people have never tried new technology masks.

Figure 22: Use of new technology masks.

When people choose masks, they usually consider the comfort (shape and respiratory comfort) and the design of the mask (appearance and fashion). In addition, the selection of mask materials is within the scope of people's consideration. Therefore, if the new technology masks meet people's requirements for the above factors, most people will choose to use the new technology masks. However, the price of new technology masks is another critical factor when people choose new technology masks. Therefore, in this survey, there is a question: if the new technology mask can meet your considerations on the comfort and design materials of the mask, but the price is higher than the traditional mask, will you consider using the new technology mask? In response to this question, 41.73% of people choose to use new technology masks, but more than half of people said they would consider whether the price is within their acceptable range, accounting for 51.08%. In addition, 7.19% believed they would never use them.

Table 1: What are your considerations in choosing masks?

Title/Options	Very little care (-2)	Don't care (-1)	Remain neutral (0)	Care about (1)	Care very much (2)
Comfort	7(5.04%)	0(0%)	10(7.19%)	54(38.85%)	68(48.92%)
Design	13(9.35%)	11(7.91%)	44(31.65%)	48(34.53%)	23(16.55%)
Material (Filtering effectiveness)	7(5.04%)	1(0.72%)	10(7.19%)	41(29.5%)	80(57.55%)
Price	8(5.76%)	2(1.44%)	36(25.9%)	63(45.32%)	30(21.58%)

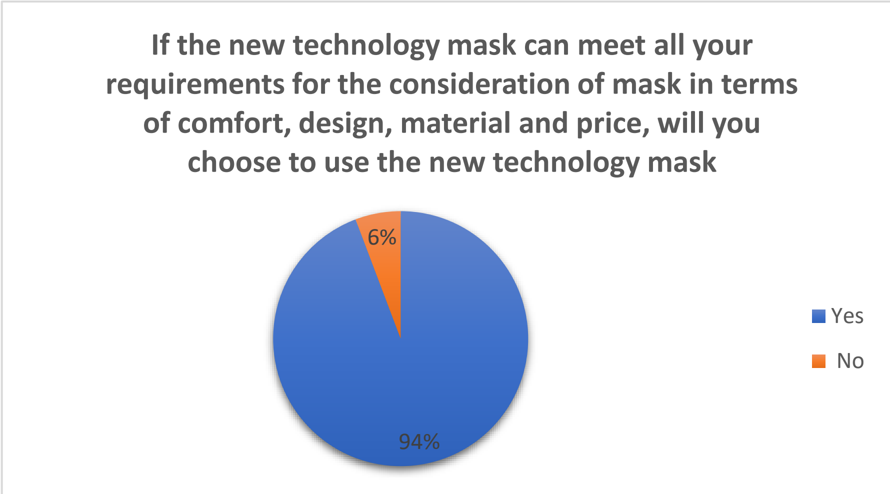


Figure 23: Acceptance of masks using new technologies.

#Part 4: Government's Efforts on the Disposal of Masks

We conducted this survey in response to the previous section on environmental challenges from discarded masks. The questionnaire ranges from general background knowledge to concerns about the environmental problems caused by today's discarded masks and government efforts. We received 51 valid responses. Of the respondents, 21.6% were under 20 years old, 66.7% were 21–20, and 11.8% were 31–40 years old.

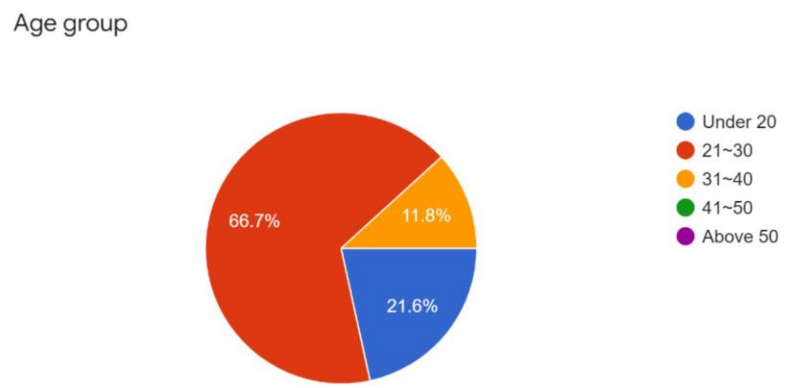
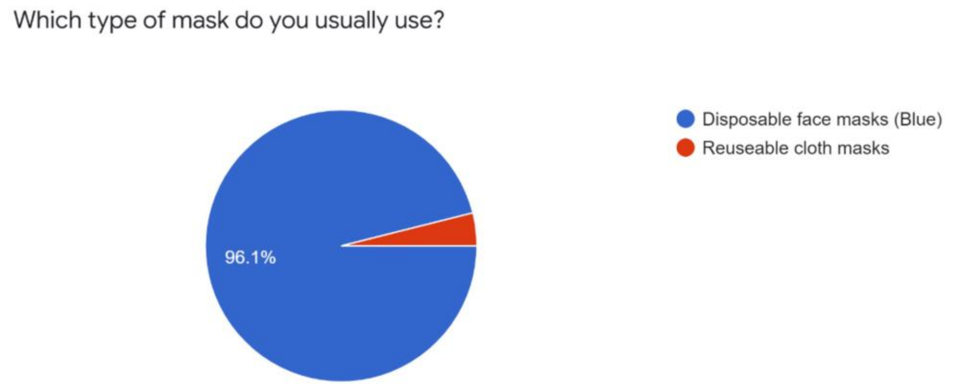
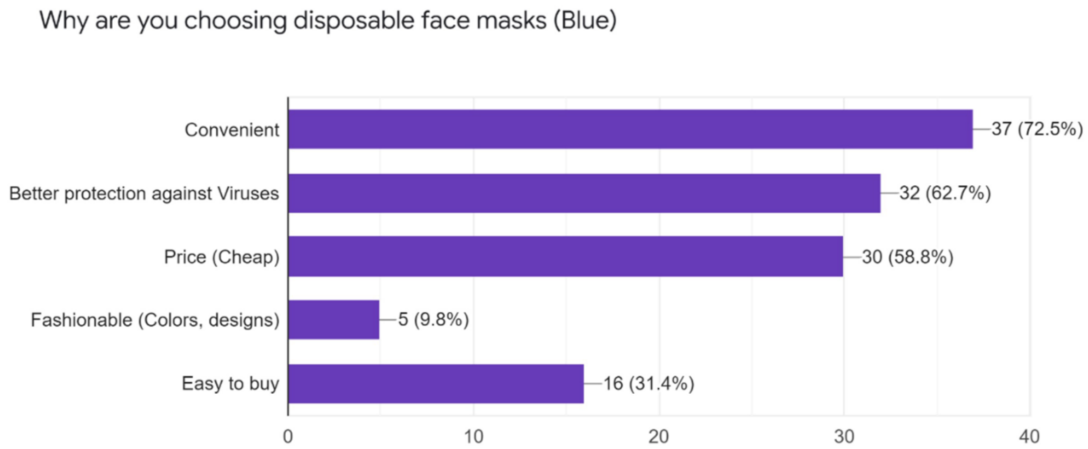


Figure 24: Personal information of the respondents.

The survey results show that 96.1% use disposable masks. After a deep probe, there are three facts that make disposable masks the mainstream choice, from personal considerations (e.g., convenience and better protection) to the market supply. Specifically, 72.5% selected because disposable masks are convenient, and 62.7% think disposable masks have good protection against viruses. Other reasons include the low price of disposable masks (35.8%), ease of buying (31.4%), and fashion color and design (9.8%). Besides, we also surveyed how often they change their masks and how to dispose of the discarded masks. The survey results indicate that 76.5% of people change masks once a day, 23.5% once every 2–3 days, and not even one responder has selected once a week. When asked how to discard the used masks, only 2% of people dispose of the masks separately, while 98% dispose of them as ordinary garbage. Moreover, fortunately, no one directly throws them in the street/outside. These results reflect that most people have a good habit of mask wearing, but the consciousness of mask discarded methods is still lacking.





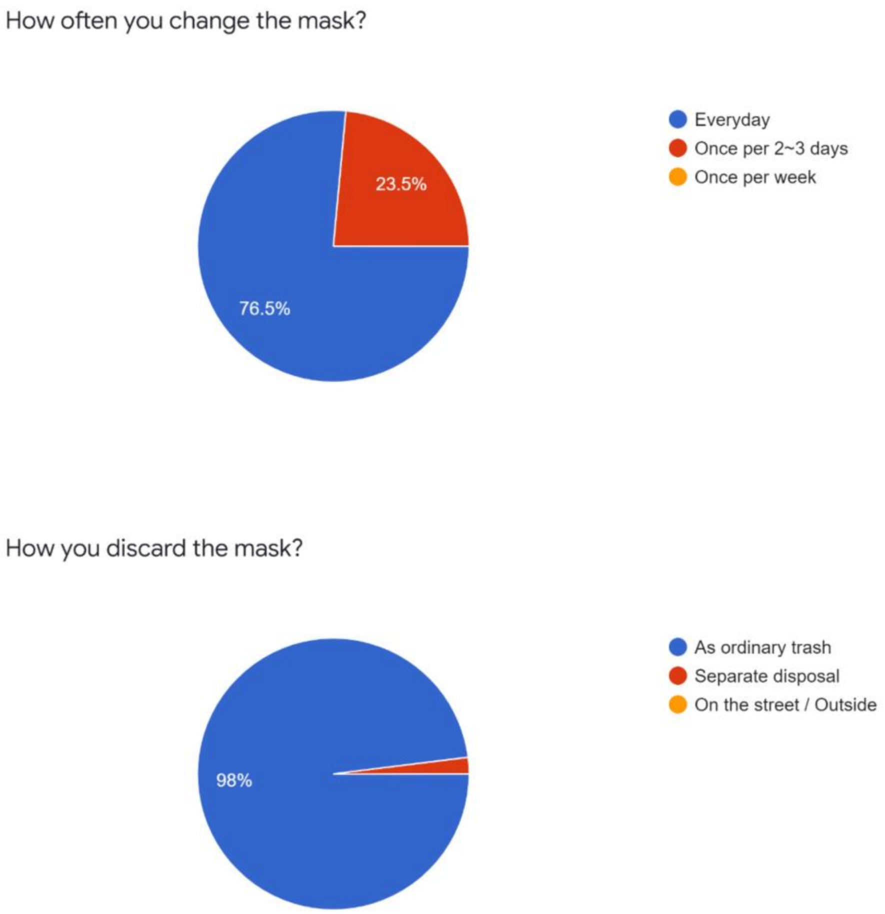


Figure 25: Mask use behavior and disposal of masks.

In the question "Your opinion about the level of the discarded face masks impacting the environment", we set the impact level of 10 points out of 10. It can be seen that most of the respondents think the impact level on the environment is high (6 or above).

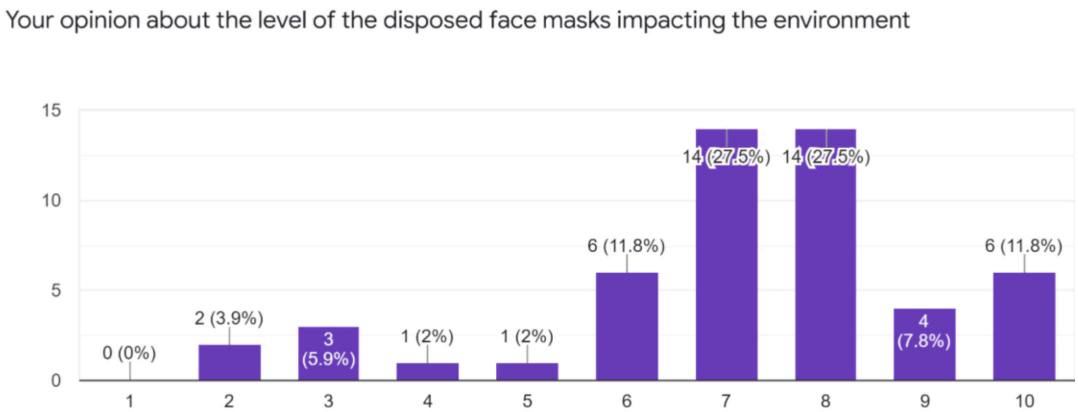
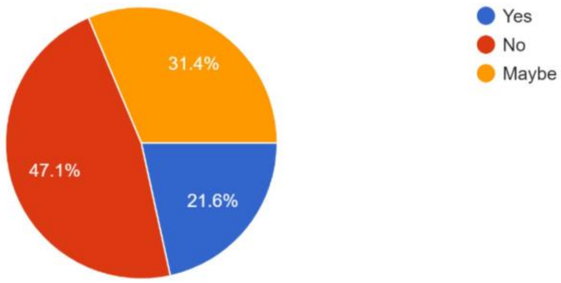


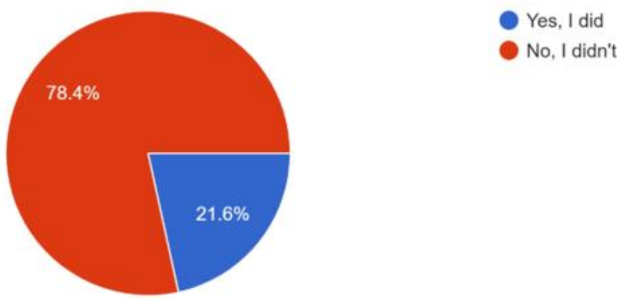
Figure 26: Opinion on how much the discarded masks impact the environment.

The percentages of people who answered "yes, no, and maybe" to the question "Would you use reusable masks if the epidemic persists" were 47.1%, 31.4%, and 21.6%, respectively. Regarding people’s opinions on how the government treats discarded masks, 78.4% said they were unsure what the government does. Among those who know what the government does, satisfaction with the government’s handling of discarded masks is uneven, with 15.8%, 26.3%, and 21.1% being satisfied with 1, 5, and 8 on a scale from 1 to 10 (satisfaction increases step by step).

Will you use reusable masks if the epidemic continues?



Did you recognize how government in your economy treats the disposed masks?



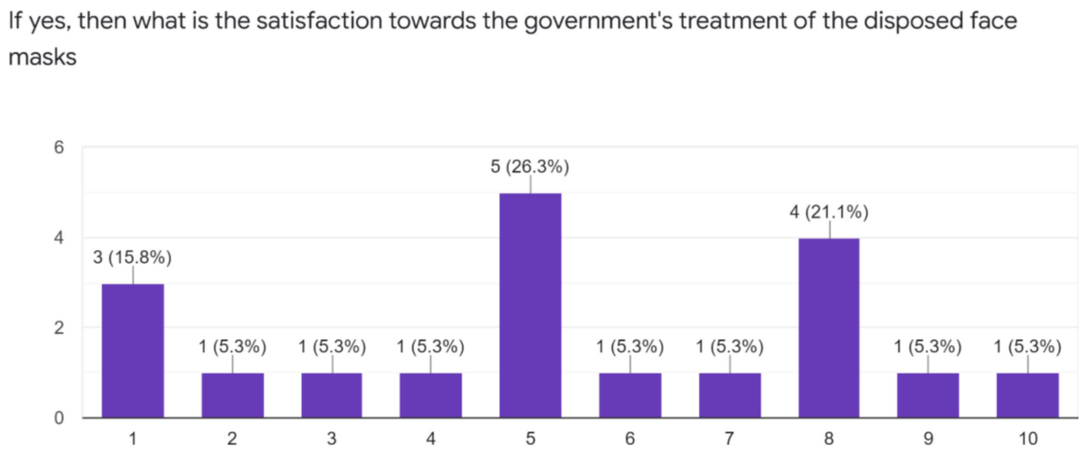


Figure 27: Government's effort to treat the disposed of face masks and reusable masks.

We also surveyed the public's opinion about the environmental pollution of masks. 56.9% of people think the pollution is concentrated in soil pollution, 37.5% of people think it occurred in ocean pollution, and 5.8% of people consider the pollution to arise in air pollution. Mask pollution does serious harm to soil, sea, and air. The improper disposal of masks through open burning or uncontrolled incineration releases harmful toxins into the environment and increases the risk of disease transmission to humans. Moreover, discarded masks often find their way into rivers and eventually reach the sea, contributing to plastic pollution in aquatic ecosystems. In marine environments, plastic waste absorbs toxins and organic contaminants, forming a toxic film on its surface. This poses a threat to marine life that may ingest the plastic materials, leading to potential poisoning. When masks end up in the soil, weathering processes generate a significant quantity of micro-sized particles (smaller than 5 mm) in a relatively short timeframe (weeks). Over time, these particles can further fragment into nano-plastics, resulting in soil pollution.

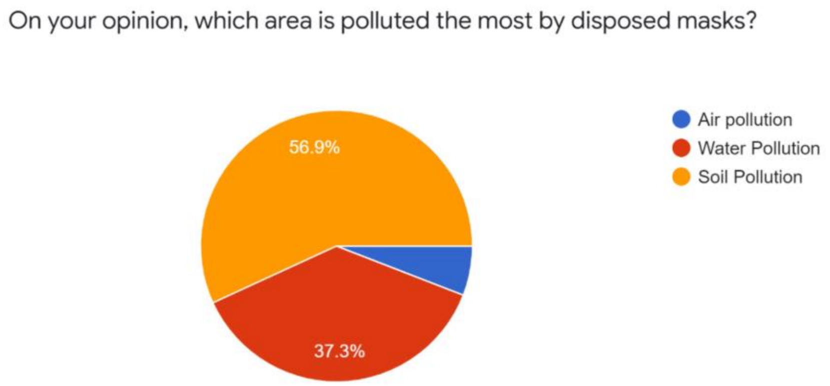


Figure 28: The area that was polluted the most by the discarded masks.

In the questionnaire "How to dispose of discarded masks to reduce the environmental impact", two solutions to the environmental problem have been proposed. More than half support remanufacturing discarded masks into practical products, and nearly half support the production of biodegradable masks. More specifically, 41.2% thought that the masks could be made biodegradable, 56.9% thought that discarded masks could be recycled into another product (e.g., plastic, bricks), and the rest thought that disposable masks could be made to last longer (more than one week).

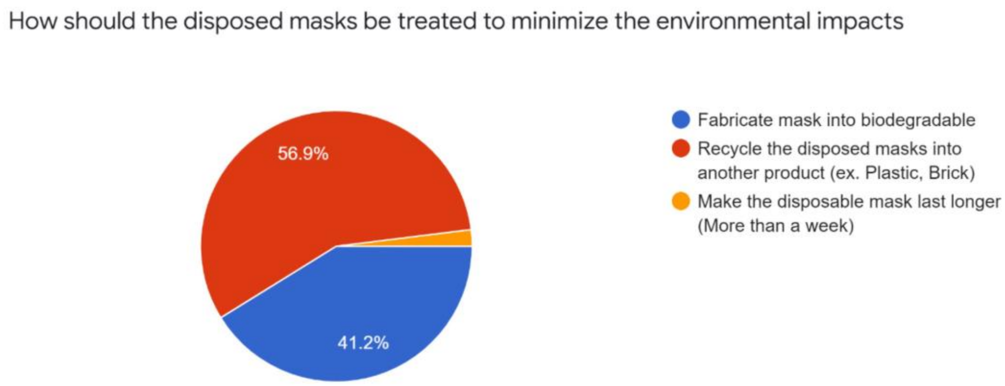


Figure 29: People's opinions on the proper way to dispose of used masks.

Since biodegradable masks are a project that may gain popularity, the questionnaire further asked about people's expectations. The responses show that it would be fully supported if the sale price of biodegradable masks is controlled below HKD4. If controlled in HKD4–8, more than half of the people (56.9%) are still willing to support it. However, according to our sources, biodegradable masks are currently at a minimum of around HKD4.2, so it is a tough road ahead. In order to know how much people know about the products recycled from disposable masks. In the survey "Do you know about products that use disposable masks for recycling?", 33.3% of people know about such products.

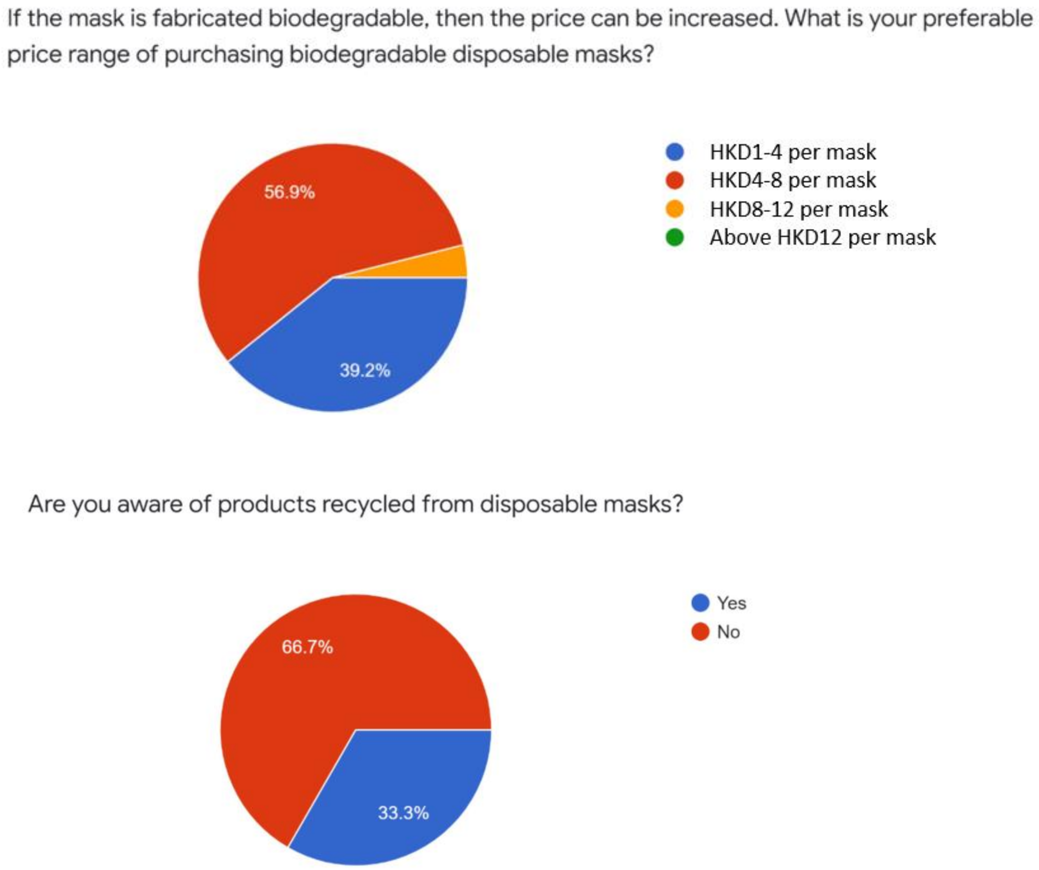


Figure 30: Biodegradable masks and recycling from the used masks.

Do people think differently about products made from discarded masks (e.g., plastic chairs, bricks, plastic boxes, etc.)? Would they accept such products? In our survey, "How do you feel about buying products made from discarded masks", we set 10 levels of influence, from smallest to largest, to indicate how much you mind such products. The survey found that 21.6% of people chose level 7, 31.4% chose level 8, and 23.6% chose levels 9 and 10.

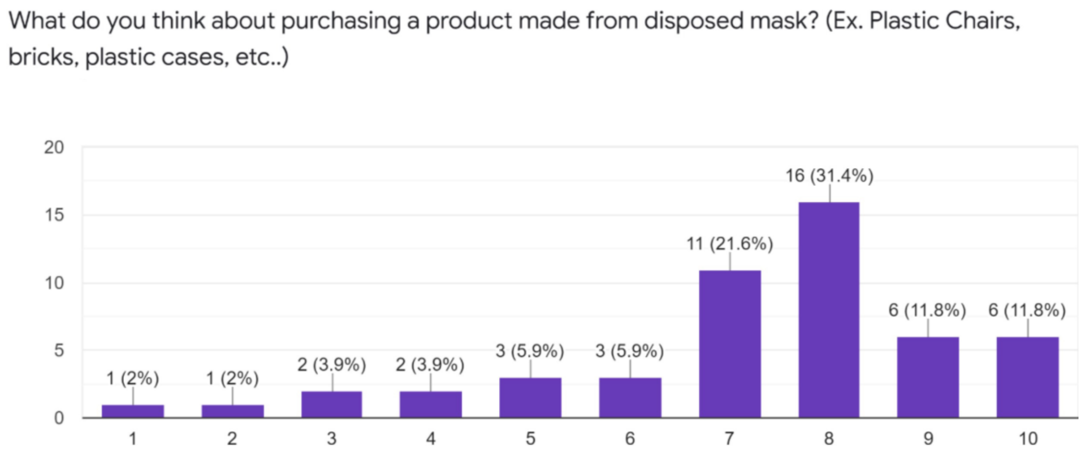


Figure 31: People's acceptance of purchasing products made from discarded masks.

#Part 5: Reusable Face Masks

From the survey results and analysis in the previous sections, it is clear that we should come up with an effective way to replace disposable masks. Reusable masks can be used multiple times to reduce the waste of masks and thus would effectively mitigate damage to the environment. However, such masks seem not common in the community. Herein, a questionnaire survey was conducted to understand the use of disposable and reusable masks and the factors that affect their choices of masks. We received 100 valid responses. Most of the participants were under 30 years old.

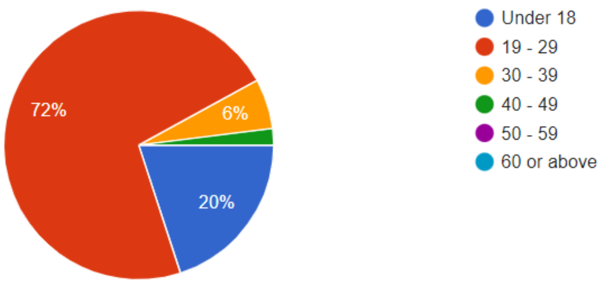


Figure 32: Age distribution of the respondents.

Of these respondents, 27% had never used any reusable mask, and only 17% used reusable masks most often. We can see that the major citizens would choose disposable masks over reusable ones. Even citizens who have used reusable masks before only use them for a short period of time.

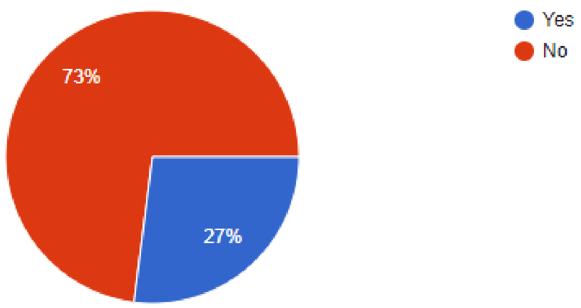


Figure 33: The number of people who have used the reusable masks.

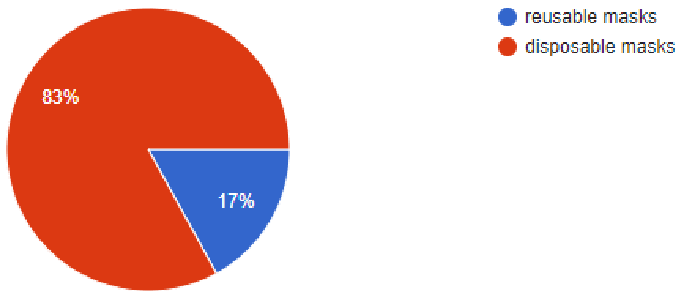


Figure 34: Types of the face masks the respondents use the most.

Among those who use disposable masks when going out, 89.2% usually wear 1 mask and 9.5% wear 2.

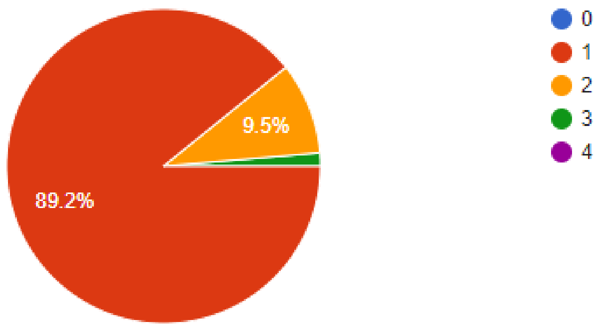


Figure 35: The number of disposable masks usually worn when going out.

For their preference for disposable masks over reusable masks, the survey results indicate that people are concerned about the protective nature of the masks, more hygiene, ease of purchase, and cost. To be more specific, protection and hygiene are their main reasons, both accounting for 75.7%. Other reasons include low cost (59.5%) and ease to get (41.9%). This suggests that citizens are thinking about their health rather than environmental friendliness in a pandemic situation. 67.1% respondents usually spend HKD0 to HKD2 for masks and 31.5% spent HKD2 to HKD5. Most of the respondents (89%) think this price is acceptable.

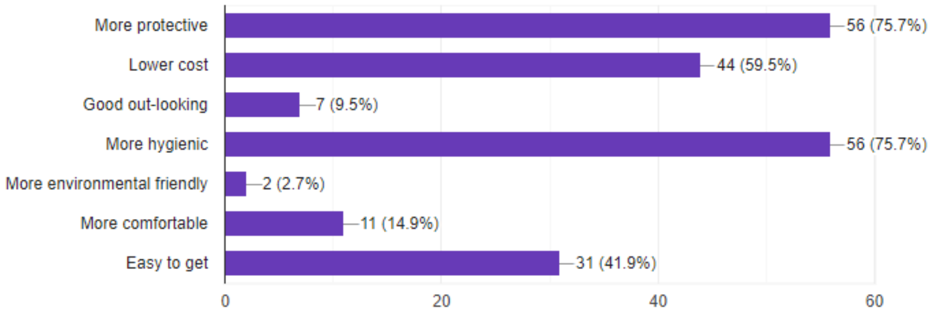


Figure 36: The reason people prefer disposable masks instead of reusable masks.

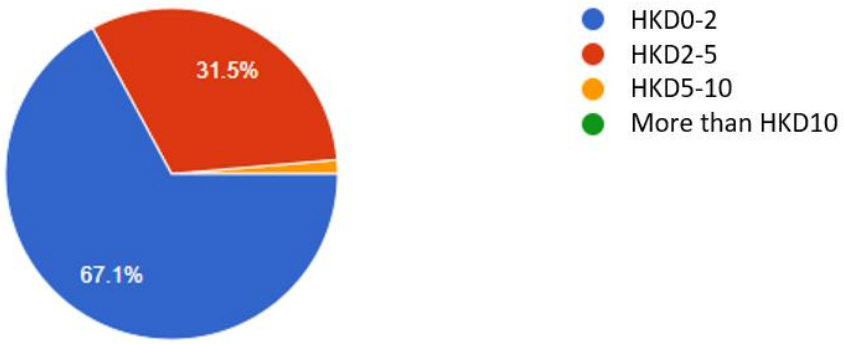


Figure 37: The money they usually spent to buy a disposable mask.

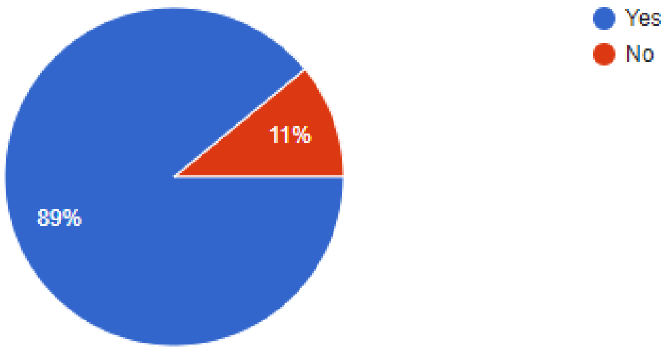


Figure 38: Price of disposable masks is reasonable or not.

Citizens who have ever used reusable masks use reusable masks much more often than disposable masks. 55.6% use reusable masks often, respondents selected sometimes and rarely are both 18.5%. Of those who choose to use such a mask, 66.7% think they would choose to use it in any scenario. The responses show that the main reason people are willing to use reusable masks is that reusable masks are more environmentally friendly and comfortable. These two factors accounted for 77.8% and 59.3% of the choices.

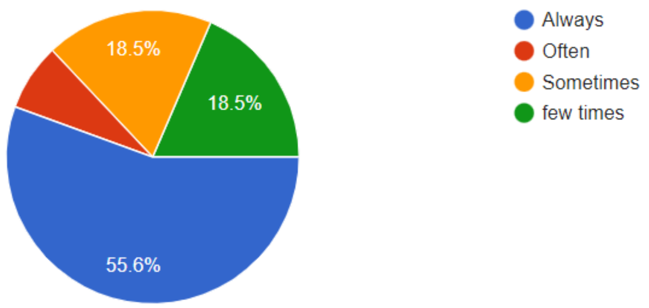


Figure 39: Frequency of using reusable masks.

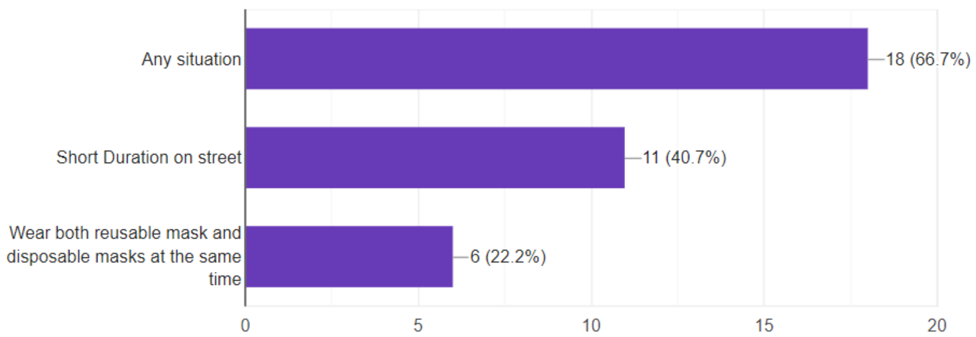


Figure 40: When would citizens like to use a reusable mask?

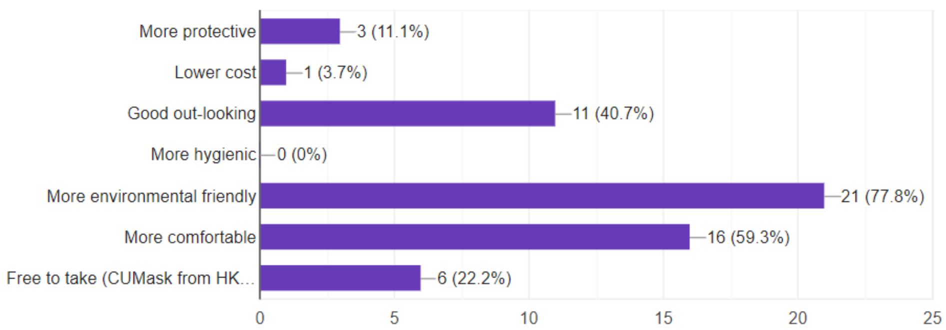


Figure 41: Reasons to prefer using reusable masks to disposable masks.

Regarding the average cost of a reusable mask, 48.1% selected higher than HKD20, while 25.9% selected between HKD0 and HKD5. Of those who have used it, 85.2% think the price of reusable masks is reasonable. For the types of reusable masks used, the percentages of CUMask, cloth masks, and pita masks (blocking dust/pollen but not viruses/bacteria) are 25.9%, 37%, and 37%, respectively.

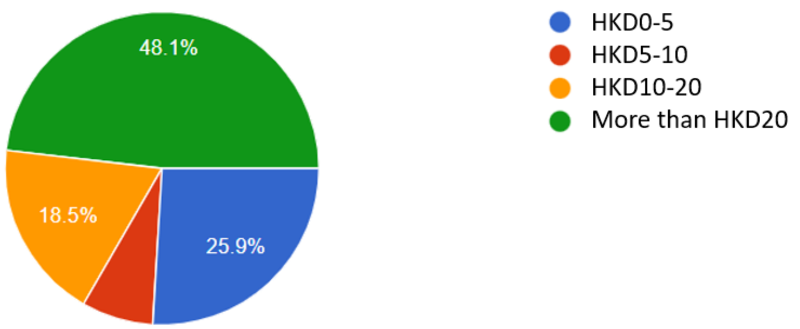


Figure 42: Average spending on a reusable mask.

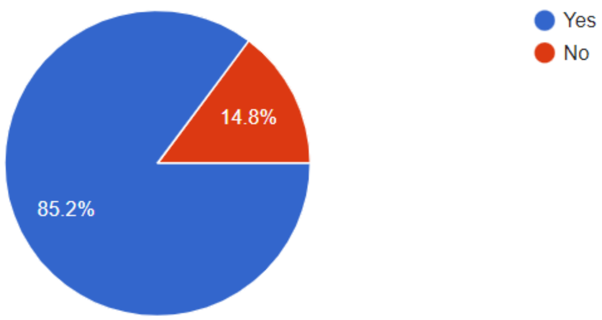


Figure 43: The price of reusable masks is reasonable or not.

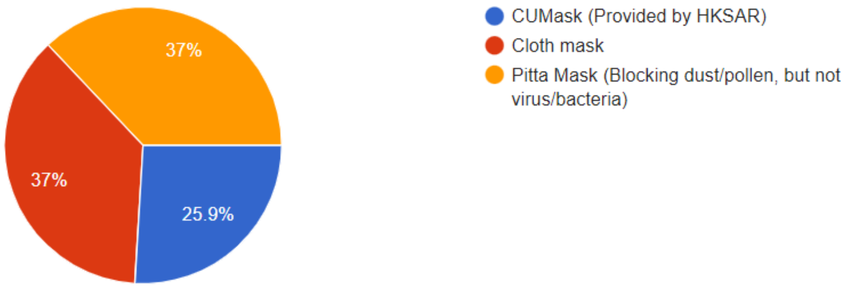


Figure 44: Types of reusable masks used.

#Part 6: Self-Charging Face Masks

The increased consumption of masks has raised concerns about their environmental impact. To meet the growing demand for masks, in addition to ordinary disposable medical masks, different types of masks, such as self-charging masks, are emerging on the market. Our previous questionnaire survey aimed to understand people's habits of mask wearing, reusable and discarding masks, and their understanding and opinions on the environmental problems caused by discarding masks. This section mainly aims to understand people's acceptance of self-charging masks in addition to the current habit of wearing masks and their cognition of disposal of discarded masks. We obtained 279 valid responses from the respondents, including 60.9% female, 39.1% male. 3.2% were under 20 years old, 38.7% between 20 and 35 years old, 34.8% between 35 and 50, and 23.3% older than 50 years old. 29.4% of the survey respondents are from Hong Kong, China, and the others are mainly from People's Republic of China.

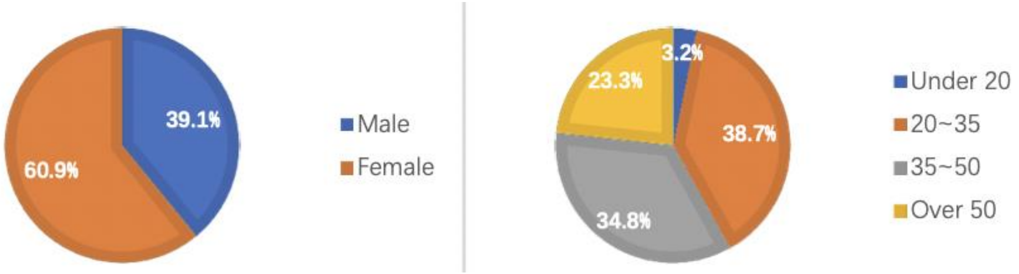


Figure 45: Basic information of the respondents.

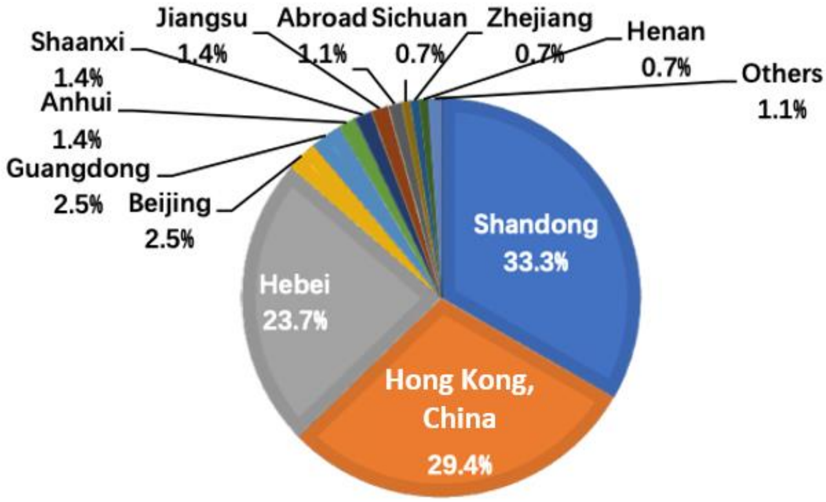


Figure 46: Regions distribution of the responders.

According to the questionnaire results, 88.9% used single-use surgical masks, and 9.7% used N95 face masks. It is worth noting that no one has ever used a self-charging face mask. However, according to a previous study[23], a self-charging mask has good air permeability. More importantly, after wearing it for 240 minutes a day for 30 consecutive days, the removal efficiency of coarse and fine particles is higher than 99.2 wt.% and as high as 86.9 wt.% for ultra-fine particles.

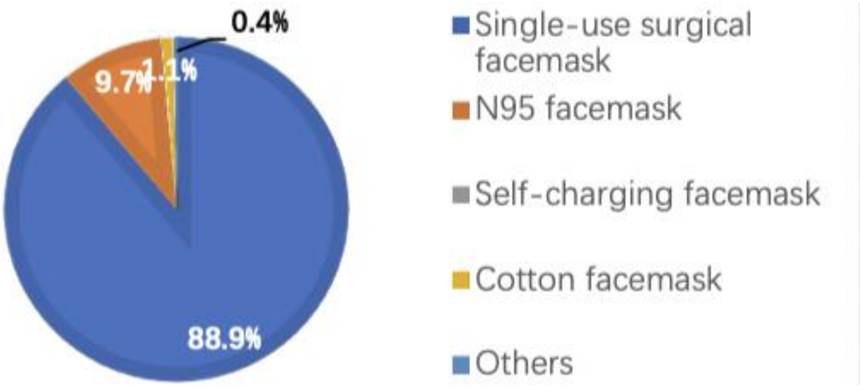


Figure 47: Types of masks that respondents use.

When asked “How often do you wear a facemask?", 89.2% said that they wear a mask frequently (more than 3 days a week) and 9.7% occasionally (less than or equal to 3 days a week). For the changing frequency of the face masks, 28.3% of people use a mask for 8 hours to 1 day, 36.2% for 1 to 2 days, and 22.2% for less than 8 hours.

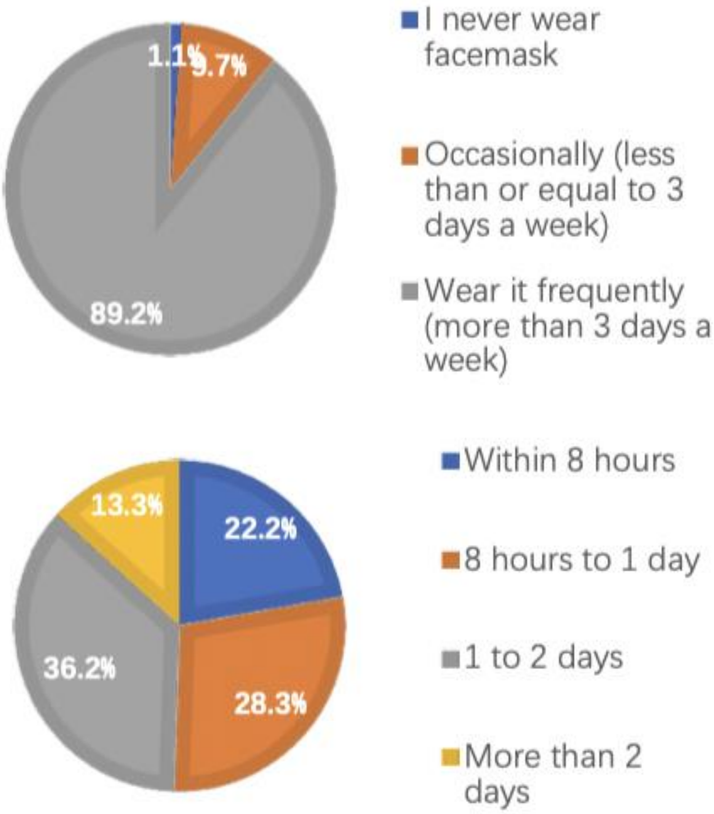


Figure 48: Mask wearing behaviors.

We also surveyed the recent new mask technology: self-charging masks. Even though 96.77% have not used such masks, they know the advantages of masks enhanced by electrostatic adsorption. 52.33% think such a mask can be self-charged by breathing, talking, and other daily activities. 42.29% think it is breathable, 38.35% think its service life will be very long, and 38.71% of people think this new mask should have a superior virus filtering ability.

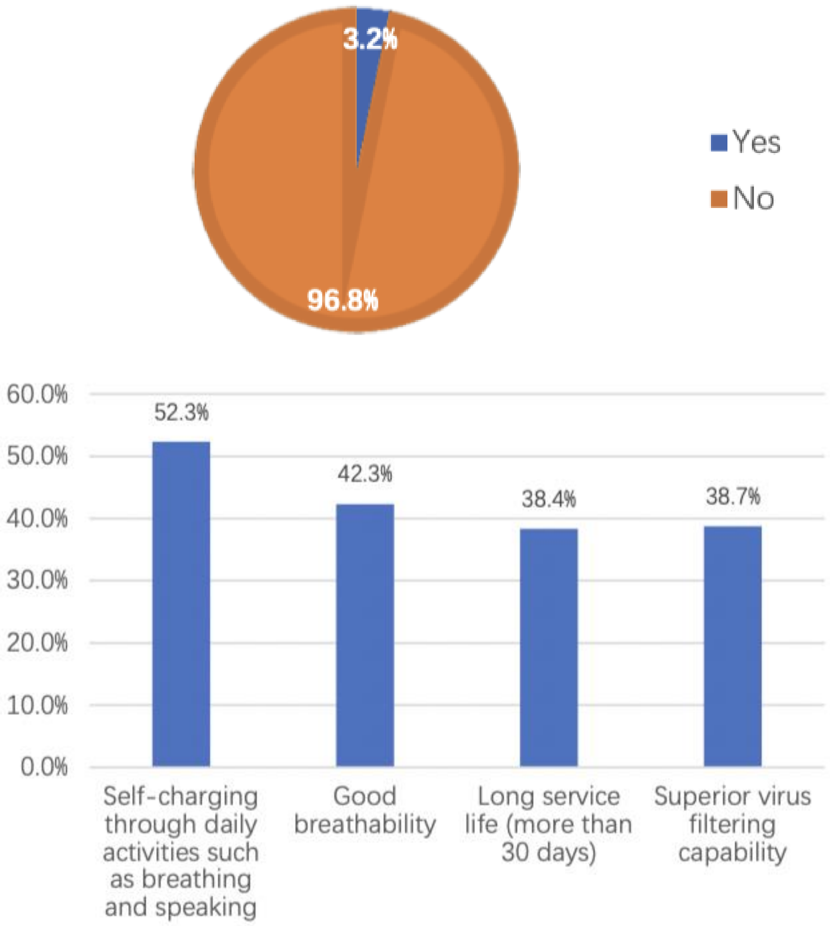


Figure 49: Use of self-charging masks and reasons.

82.1% of the respondents believe self-charging masks can, to some extent, alleviate the environmental pollution caused by disposable surgical masks, and 82.8% think it is necessary to continue to develop self-charging facemasks. As long as the price is lower than HKD50, 85.4% (64.26% prefer less than HKD20) of people choose to buy self-charging masks.

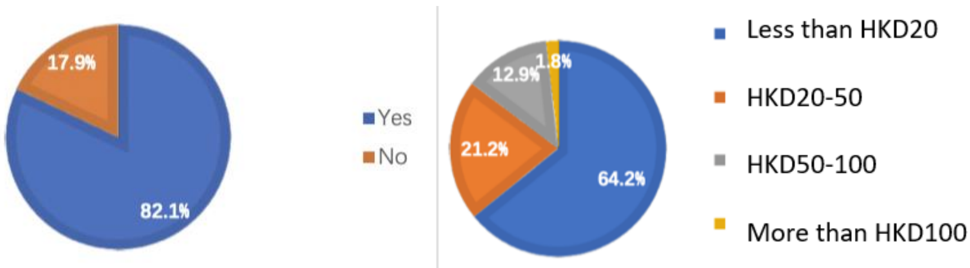


Figure 50: Acceptance of self-charging masks.

Key findings and conclusions

In summary, the survey results show that masks have become increasingly common in Hong Kong, China in recent years, but many people have not mastered the proper way to wear masks. Understanding the scientific knowledge of masks is conducive to correctly using masks. However, most people do not know the specific protective mechanism, structure, index parameters, or evaluation system of masks. Therefore, it is important to popularize the proper wearing method and filtration mechanism of masks, for example, by carrying out publicity of mask popular science short films in the media and attaching knowledge leaflets on the correct use of masks in the channels where people often buy masks (e-commerce and physical supermarkets). In addition, quite a few people are not very satisfied with the wearing comfort of masks, which may cause improper wearing and low protection. Therefore, it is necessary to optimize the design in terms of the compatibility, structure, and materials of the masks, which will contribute to facilitating the implementation of epidemic prevention.

Under the current epidemic of COVID-19, a large number of discarded masks have seriously polluted the environment and caused a waste of resources. This problem can be solved by popularizing environmentally friendly masks, such as reusable and biodegradable ones. Even though the questionnaire results show that people are concerned about the environmental issues caused by discarded masks and are interested in mask products using new technologies, there is not a positive trend for the responders to use such masks. We have found a couple of reasons that they are unwilling to use reusable masks even though the COVID-19 pandemic has lasted for two years. The primary reason citizens use disposable masks instead of reusable masks is the protection efficiency of reusable masks in blocking viruses or bacteria, especially after using an extended period. The cost is another critical factor that affects public acceptance of environment-friendly masks. Given that the price is reasonable, green technologies are highly preferred.

Regarding another new technology of masks, i.e., self-charging masks, most people have not used them yet, but they generally think that the development of this new technology is necessary, which shows that people are very much looking forward to new means to solve the problems brought by traditional masks such as wearing discomfort and pollution of the environment.

The results of this report can provide a reference for decision-makers to think about environmental impacts when making decisions and also guide the public on the selection and use of masks. We hope this investigation can contribute to the prevention and control of COVID-19.

Online Seminar

<u>Preparation</u>

Preparations before Online Seminar include developing an activity plan, inviting keynote speakers, creating a website, establishing a seminar schedule (Appendix B), and designing promotional posters (Appendix C).

<u>Online Seminar</u>

#Topic 1: Face Masks in the New COVID-19 Normal: Materials, Testing, and Perspectives

Prof. Loh Xian Jun, Agency for Science, Technology and Research (A*STAR)

Prof. Loh presented his research on masks in the context of the new normal during the COVID-19 pandemic. The goal was to enhance the safety of frontline medical personnel when caring for patients. They developed a mask with integrated remote monitoring capabilities (**Figure 51**). This innovative mask can simultaneously monitor multiple key health parameters relevant to pneumonia, including heart rate, blood pressure, and blood oxygen saturation in real-time.

To ensure biocompatibility, a crucial aspect for a mask of this nature, they chose to encase the entire system in polydimethylsiloxane (PDMS), a common material for flexible electronics. Uniaxial stress tensile tests demonstrated that PDMS has a significantly lower Young's modulus compared to masks and printed circuit boards. This characteristic enhances wearing comfort and provides stable signal output.

Prof. Loh also shared the results of practical measurements. When compared to commercial testing equipment, this intelligent mask can effectively monitor various patient data over an extended period, reaching a level of performance on par with established commercial equipment.

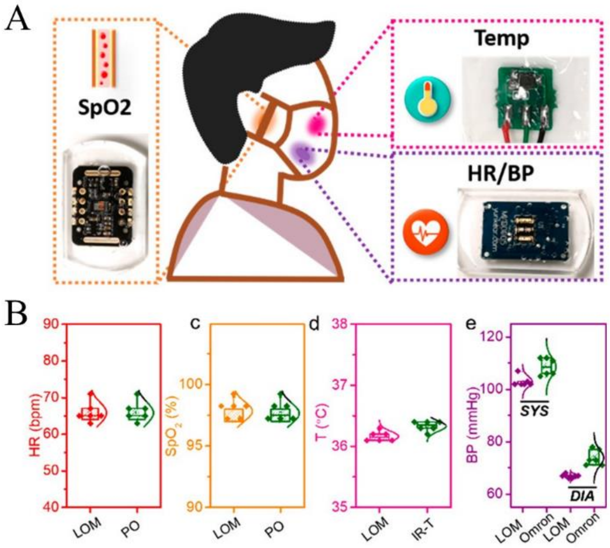


Figure 51: The mask with monitoring function.

#Topic 2: A Nano-Composite Sensor Integrated AI-Mask for Tracking Multiphase Respiratory Activities
Prof. Li Wen Jung, City University of Hong Kong

Prof. Li introduced their latest advancements in "smart masks". These masks are capable of detecting various respiratory sounds associated with breathing, speaking, and coughing, thereby enabling continuous health monitoring in everyday life (**Figure 52**).

The flexible sponge-based sensor in this study was crafted from a nanocomposite of carbon nanotubes and PDMS. Prof. Li elaborated on the sensor's fabrication process and performance characteristics. Experimental findings revealed that parameters such as carbon nanotube properties, Young's modulus, and porosity significantly influence the performance and sensitivity of the piezoresistive sensor. The sensor's performance can be further enhanced based on theoretical analyses.

Notably, the sensor exhibits excellent high-frequency acoustic performance, offering a rapid response to detect sound signals generated by human speech. Furthermore, the research delved into studying the sensor's response to airflow direction and vibration. Results indicated that both types of airflow can be effectively detected. Directional airflow produced irregular signals, with energy concentrated in the low-frequency range. Conversely, periodic signals stemming from air vibration exhibited energy concentration at the vibration frequency, including fundamental frequency and corresponding harmonics.

Upon completing the sensor-related work, it was seamlessly integrated into a mask, successfully detecting airflow patterns associated with breathing, coughing, and speaking. Subsequent real-world testing on subjects validated the mask's ability to monitor respiratory activities in daily life.

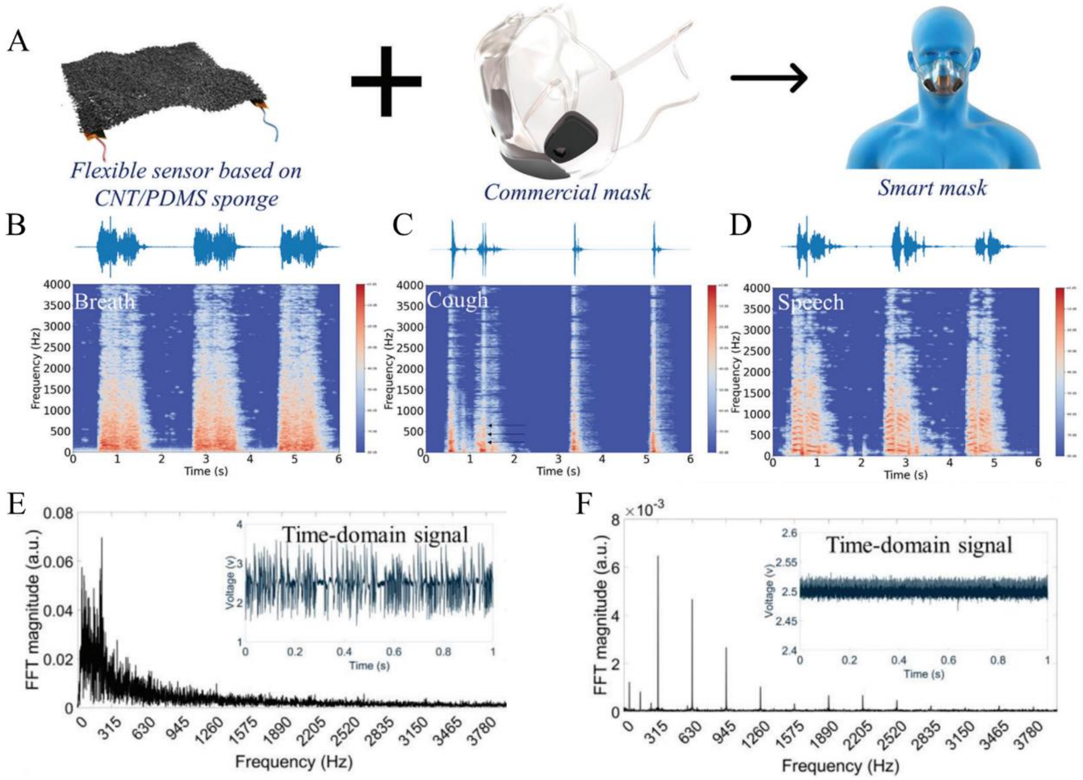


Figure 52: Smart mask with a nano-composite sensor.

#Topic 3: Development of a Reusable and Comfort Facemask as a Barrier to Microorganisms
Dr. Yao Lei, Hong Kong Research Institute of Textiles and Apparel (HKRITA)

Dr. Yao introduced us to the CuMask+ developed by her team for distribution to the people of Hong Kong, China during the COVID-19 pandemic (**Figure 53**A). She began by outlining the original design goals of the mask, which included filtration efficiency, antibacterial properties, and most importantly, reusability. To achieve effective filtration at a low cost, the mask incorporates a multi-layer melt-blown polypropylene fiber membrane, a material readily available in the commercial market. Additionally, to address the pressing needs during the COVID-19 crisis, the mask features copper elements. Minute copper oxide particles adhere to the polypropylene fibers, providing the mask with sterilizing capabilities. CuMask+ not only extends the service life of individual masks but also reduces waste through multiple washes. To safeguard the integrity of the fibers during washing, Dr. Yao's team added two protective layers outside the central filter and antibacterial layer (**Figure 53**B).

Dr. Yao also described how CuMask+ transitioned from laboratory development to commercial production following the COVID-19 outbreak, aiding Hong Kong, China citizens in their fight against the pandemic. In a short span, they conducted feasibility tests on various materials and overcame numerous challenges in the mass production phase, including sourcing raw materials and selecting suitable factories. Ultimately, over 10 million CuMask+ were manufactured and distributed free of charge to ordinary residents of Hong Kong, China by the government.

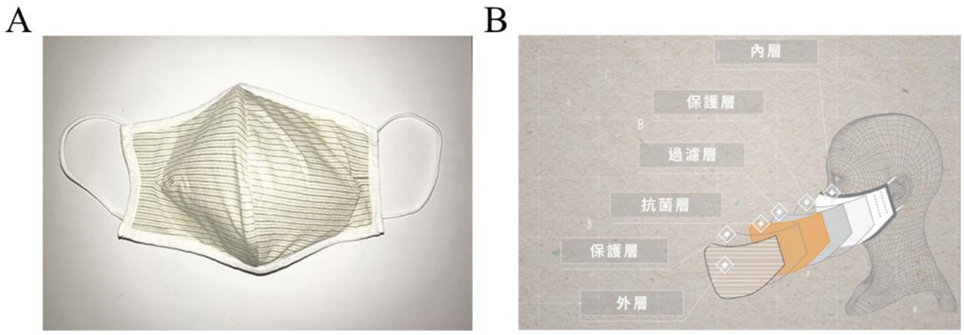


Figure 53: Appearance and structure of CuMask+

#Topic 4: Face masks for respiratory tract viral infections: what are the evidences?
Dr. Jasper Fuk-Woo Chan, University of Hong Kong

As a clinical microbiologist specializing in emerging infectious diseases, Dr. Chan promptly initiated a family cluster study at the onset of the COVID-19 pandemic. His investigation centered around a family of six individuals who had recently traveled from Shenzhen to Wuhan. This study unearthed crucial findings, demonstrating that the novel coronavirus could be transmitted among individuals both within households and hospitals, as well as between different cities. Notably, the symptoms of this new pneumonia were found to be nonspecific. Multifocal ground-glass changes observed on lung CT scans emerged as a common characteristic of viral pneumonia. Furthermore, Dr. Chan's research identified the potential existence of asymptomatic patients during the early stages of the outbreak.

Dr. Chan also shared a groundbreaking study on the role of surgical masks in mitigating the spread of COVID-19 (**Figure 54**). This study provided the first in vivo experimental evidence supporting the potential effectiveness of surgical masks, especially when worn by infected individuals, in preventing COVID-19 transmission. Initially, the research demonstrated non-contact transmission of SARS-CoV-2 within a Syrian hamster model. Subsequently, the study assessed the efficacy of surgical mask partitions in reducing the risk of non-contact transmission. The findings unequivocally demonstrated that the use of surgical mask partitions led to a substantial reduction in infection rates. This was further confirmed through histopathological changes and the expression of respiratory virus N antigen, providing additional evidence of surgical mask effectiveness. The study underscored that the virus was transmitted via the non-contact route of respiratory droplets or air droplet nuclei, with masks effectively filtering out larger respiratory droplets.

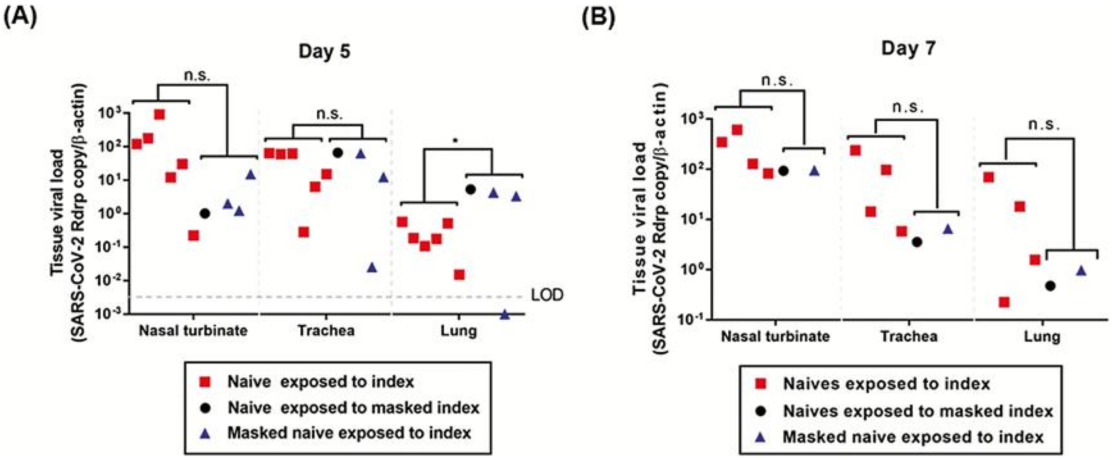


Figure 54: The effect of mask in COVID-19.

#Topic 5: Flexible Nanoporous Template for the Design and Development of Reusable Anti-COVID-19 Hydrophobic Face Masks
Dr. Nazek El-Atab, King Abdullah University of Science and Technology (KAUST)

Dr. Nazek El-Atab provided insights into her recent research and perspectives on mask technology. She emphasized the pivotal role of nanotechnology in effectively addressing the ongoing epidemic by enabling the development of safer, more durable, environmentally friendly, and cost-effective masks through simple manufacturing processes. Studies have consistently demonstrated that nanofibers, particularly those with diameters ranging from 100 to 500 nm, exhibit superior capture efficiency in filtering sub-micron particles compared to microfibers.

Electrospinning, a widely employed nanofiber manufacturing technique, offers the advantage of introducing various properties and functionalizations during the spinning process. For instance, the incorporation of silica nanoparticles imparts electric charge to the fibers, enhancing the mask's mechanical strength and electrostatic attraction capabilities. Triboelectric charging is another common method used to charge masks effectively. Furthermore, surface treatments applied to nanofibers can render them antibacterial, antiviral, hydrophobic, and more.

Dr. Nazek El-Atab also shared advancements related to antiviral masks (**Figure 55**). In contrast to traditional nanofiber masks with larger diameters that face challenges in effectively filtering viruses, nanoporous templates have emerged as a superior alternative. These templates are fabricated using MEMS technology. Variations in etching time, concentration, thickness, and other conditions yield different pore sizes. Theoretical assessments of airflow rates indicate that these membranes maintain breathability across a broad range of pore sizes, densities, membrane thicknesses, and pressure drops. Multiple patterning steps can be employed to enhance porosity and increase the allowable air flow rate without compromising filtration efficiency.

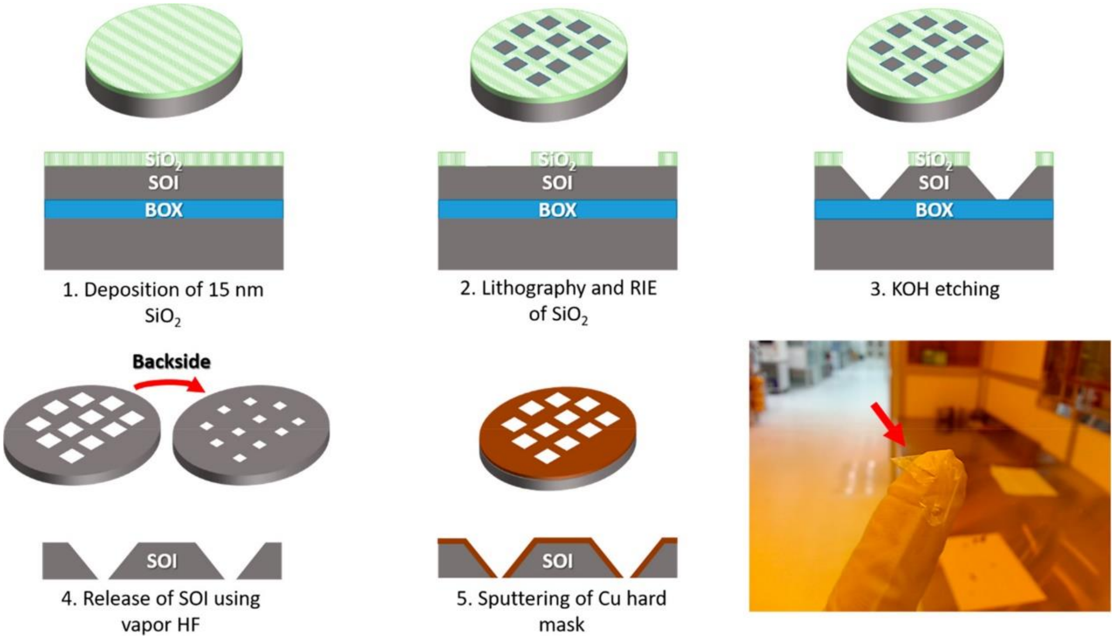


Figure 55: The fabrication of nanoporous templates.

#Topic 6: Piezoelectric Nanofiber Membrane for Reusable, Stable and Highly Functional Face Mask Filter with Long-Term Biodegradability
Dr. Thanh D. Nguyen, University of Connecticut

Dr. Nguyen presented a fascinating research endeavor on face masks (**Figure 56**) aimed at mitigating the issue of performance degradation in traditional masks under humid conditions. To address this challenge, they leveraged poly(l-lactic acid) (PLLA), an emerging piezoelectric polymer material, utilizing electrospinning technology to craft nanofiber membranes. Comparative analysis revealed that PLLA masks outperformed poly(d,l-lactic acid) (PDLLA) masks, which lack piezoelectric properties, in terms of filtration efficiency. Dr. Nguyen also elucidated the influence of various parameters on mask performance, including receiver rotation speed, electric field, and the number of holes.

Notably, due to its inherent piezoelectric characteristics, PLLA masks exhibited significantly less performance degradation when exposed to moisture compared to surgical and N95 masks, as the latter rely on electrostatic charges generated on their surfaces for filtration. The self-charging properties of the piezoelectric material enabled prolonged and efficient use of the mask. Dr. Nguyen further highlighted the mask's antibacterial attributes, reusability, and degradability. Experimental results underscored the mask's remarkable antibacterial performance, reusability, and its ability to biodegrade effectively in soil and concentrated buffers.

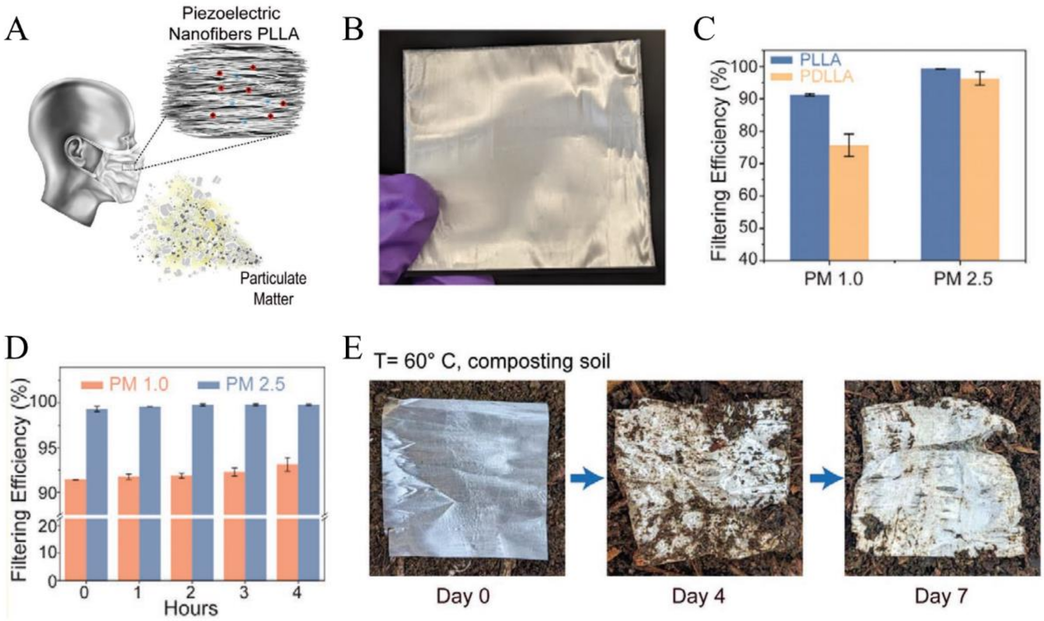


Figure 56: Piezoelectric face masks.

Summary

The COVID-19 pandemic has shifted the spotlight to the significance of face masks, emphasizing their crucial role in curbing the virus's spread. The past year witnessed an upsurge in research and community-driven initiatives focused on enhancing face mask technologies. This proliferation of research, while promising, has brought about complex data filled with gaps and contradictions.

To navigate this intricate landscape, a comprehensive review of face masks was conducted. This review aims to provide a solid foundation for understanding various aspects of face mask technologies, including filtration mechanisms, manufacturing methods, filtration performance, and antimicrobial features. The goal is to bridge the gap between scientific research and practical use, offering insights to guide the selection and use of face masks. This systematic review synthesizes the complexities surrounding face masks and serves as a knowledge repository for making informed decisions about their usage across different contexts. As the world adapts to new norms in the wake of the pandemic, face masks remain a fundamental tool in protecting public health.

A community survey was carried out to obtain real-world insights into face mask usage and efficacy in China and Hong Kong, China. The survey aimed to reveal user habits, gauge public understanding of the environmental impact of discarded face masks, and gather opinions on the development of new mask technologies. With 934 valid online responses, this survey provided valuable firsthand information.

To amplify the project's impact, an inclusive Online Seminar was organized and made accessible to APEC economies, ensuring broader dissemination of the study's findings and the promotion of innovative face masks in society.

In conclusion, this project endeavor comprised a systematic review, a community survey, and an inclusive Online Seminar. Together, these efforts sought to address the multifaceted challenges and opportunities related to face masks during the pandemic. The overarching objective is to facilitate the integration of new mask technologies into public health strategies, even in the face of ongoing uncertainties. Face masks remain a critical tool in our fight against the evolving challenges posed by the pandemic.

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Appendices

Appendix A: Questionnaire

APEC Survey Report on Mask Usage Behaviors and Protective Efficacy Awareness in China and Hong Kong, China

(APEC Project: LSIF 01 2021)

Part 1. Use of Face Masks and Public Perceptions of Mask Protection Efficacy

1.1 Age group distribution

☐ Under 18	☐ 18–24	☐ 25–34
☐ 35–44	☐ 45–54	☐ 55–64
☐ 65 or above		

1.2 Gender

☐ Male	☐ Female

1.3 Region

☐ People's Republic of China	☐ Hong Kong, China	☐ United Kingdom
☐ Others		

1.4 Which types of face mask do you prefer?

☐ Surgical mask	☐ Dust msk (e.g. Pitta masks, cotton masks)	☐ Activated charcoal masks

1.5 What occasions do you wear a face mask?

☐ At home	☐ Indoor public places where social distance cannot be maintained
☐ All public places	☐ Outdoor public places where social distance cannot be maintained

1.6Would you still wear face mask if it is not mandatory?

☐ Yes	☐ No	☐ Maybe

1.7 How many face masks did you use in the past 7 days?

☐ 3 or less	☐ 4 to 6	☐ 7 to 10
☐ 11 to 14	☐ 15 or more	

1.8 How many times do you change your face masks a day?

☐ Once only	☐ Twice	☐ Three times or above

1.9 When wearing a face mask, what would you care more about?

☐ Can cover the mouth	☐ Can cover the nose	☐ Can cover both mouth and nose
☐ No gaps between face and mask	☐ Ventilation of mask is good	☐ Do not care any of those

1.10 Do you agree that one of the most effective ways to curb the virus spread is wearing face masks?

☐ Strongly agree	☐ Agree	☐ Neutral
☐ Disagree	☐ Strongly disagree	

1.11 How well do you know about protective efficacy (e.g., PFE, VFE, BFE) of a face mask?

☐ People's Republic of China	☐ Hong Kong, China	☐ Other regions

1.12 How well do you know about the filtration mechanism (i.e., inertial impaction, interception diffusion and electrostatic attraction) of face masks?

☐ Very familiar	☐ Familiar	☐ No ideas at all
☐ Average	☐ Not familiar	

1.13 Have you ever been infected with virus under wearing a face mask?

☐ Yes	☐ No	☐ Maybe

Part 2. Mask Wearing Behaviors and Improvement Measures

2.1 What's your gender?

☐ Male	☐ Female

2.2 Age group distribution

☐ 18–22	☐ 22–25	☐ 25–30
☐ 30 or more		

2.3 What is the average frequency of going to public places?

☐ hardly ever	☐ 1–2 times a week	☐ 3–4 times a week
☐ almost every day		

2.4 If you wear a disposable medical surgical mask, how often do you change it?

☐ Change no more than once every 8 hours	☐ Change no more than once every 4 hours
☐ Replace when breathing resistance becomes high	☐ Depending on the crowd density of the location

2.5 Does the inside of the mask often become contaminated with moisture from talking or movement?

☐ Each time	☐ Frequently
☐ Occasionally	☐ Never

2.6 Which type of mask do you prefer to use?

☐ Medical surgical masks	☐ KF94 Anti-epidemic mask
☐ N95 valveless masks	☐ Other Mouthpieces

2.7 Under which circumstances do you push your mask under your chin?

☐ Eating	☐ Apply lipstick
☐ Poor breathing due to physical problems	☐ Other

2.8 Do you clean your hands before and after wearing a mask?

☐will	☐ No

2.9 After removing the mask, do you touch the external surface of the mask?

☐ Never, only removed by ear hooks or ties	☐ Yes, but basically sleep immediately using	☐ Always have contact

	alcohol disinfection	

2.10 Do you understand that skin-friendly nonwoven, meltblown nonwoven, and waterproof Onyx layer nonwoven are the three layers of mask structure?

☐ Not at all	☐ Unfamiliarity	☐ General
☐ Familiarity	☐ Very familiar	

2.11 Do you understand the relationship between the model numbers of masks (e.g. FFP3, FFP2, N95, KN90) and their origin and protection capacity, which are composed of letters + numbers?

☐ Not at all	☐ Unfamiliarity	☐ General
☐ Familiarity	☐ Very familiar	

2.12 Do you know the main measurement indicators of masks (e.g. PFE, BFE)?

☐ Not at all	☐ Unfamiliarity	☐ General
☐ Familiarity	☐ Very familiar	

2.13 Do you know that electrostatic adsorption is the main reason why masks work?

☐ Not at all	☐ Unfamiliarity	☐ General
☐ Familiarity	☐ Very familiar	

2.14 Do you have any knowledge about the reuse technology of masks?

☐ Not at all	☐ Unfamiliarity	☐General
☐ Familiarity	☐ Very familiar	

Part 3. Environmental Challenges from Discarded Face Masks and Public Knowledge on New Technology Masks

3.1 What's your gender?

☐ Male	☐ Female

3.2 What region do you live in now?

☐ People's Republic of China	☐ Hong Kong, China	☐ Other regions

3.3 What is your age?

☐ Under 18	☐ 18–24	☐ 25–34
☐ 35–44	☐ 45–54	☐ 55–64
☐ Above 65		

3.4 What types of masks do you use?

☐ Surgical mask	☐ N95 mask	☐ Cloth mask
☐ Reusable mask	☐ Others	

3.5 Do you know what brands of face masks are on the market?

☐ Yes	☐ No

3.6 Do you find a lot of discarded masks in your region?

☐ Yes	☐ No

3.7 Do you think a lot of discarded masks cause waste?

☐ Yes	☐ No

3.8 Have you ever used masks with new technologies (mainly referring to green environmental protection, such as degradable masks, reusable masks, etc.)?

☐ Yes	☐ No

3.9 Have you ever used masks with new technologies (mainly referring to green environmental protection, such as degradable masks, reusable masks, etc.)?

☐ Yes	☐ No

3.10 What are your considerations in choosing masks?

	Very little care (−2)	Don't care (−1)	Remain neutral (0)	Care (1)	Care very much (2)
Comfort (shape, breathing comfort)	☐	☐	☐	☐	☐
Design (mask appearance, fashionability)	☐	☐	☐	☐	☐
Material (Filtering effectiveness)	☐	☐	☐	☐	☐
Price	☐	☐	☐	☐	☐

3.11 If the new technology mask can meet your considerations on the comfort, design and materials of the mask, but the price is higher than the traditional mask, will you choose to use the new technology mask?

☐ Yes	☐ No

3.12 Would you choose to use a new technology mask if it could meet all your requirements in terms of comfort, design, materials, price, etc.?
If the new technology mask can meet all your requirements for the consideration of mask in terms of comfort, design, material and price, will you choose to use the new technology mask?

☐ Yes	☐ No

Part 4. Government's Efforts on the Disposal of Masks

4.1 Age group

☐ Under 20	☐ 21–30	☐ 31–40
☐ 41–50	☐ Above 50	

4.2Which type of mask do you usually use?

☐ Disposable face masks	☐ Reusable cloth masks

4.3 Why are you choosing disposable face masks?

☐ Convenient	☐ Easy to buy	☐ Price (Cheap)
☐ Fashionable (Colors, designs)	☐ Better protection against Viruses	

4.4 How often you change the mask

☐ Everyday	☐ Once per 2–3 days	☐ Once per week

4.5 How do you discard the mask?

☐ As ordinary trash	☐ Separate disposal	☐ On the street/ Outside

4.6 Your opinion about the level of the disposed face masks impacting the environment (Increasing influence from one to ten).

☐ 1	☐ 2	☐ 3
☐ 4	☐ 5	☐ 6
☐ 7	☐ 8	☐ 9
☐ 10		

4.7 Will you use reusable masks if the epidemic continues?

☐ Yes	☐ No	☐ Maybe

4.8 Did you recognize how government in your economy treats the disposed masks?

☐ Yes, I did	☐ No, I didn't

4.9 If yes, then what is the satisfaction towards the government's treatment of the disposed face masks (Increasing influence from one to ten)?

☐ 1	☐ 2	☐ 3
☐ 4	☐ 5	☐ 6
☐ 7	☐ 8	☐ 9

☐ 10		

4.10 On your opinion, which area is polluted the most by disposed masks?

☐ Air pollution	☐ Water Pollution	☐ Soil Pollution

4.11 How should the disposed masks be treated to minimize the environmental impacts?

☐ Fabricate mask into biodegradable	☐ Recycle the disposed masks into another product (e.g., Plastic, Brick)	☐ Make the disposable mask last longer (More than a week)

4.12 If the mask is fabricated biodegradable, then the price can be increased. What is your preferable price range of purchasing biodegradable disposable masks?

☐ USD0.1–0.5 (HKD1–4) per mask	☐ USD0.5–1 (HKD4–8) per mask
☐ USD1–1.5 (HKD8–12) per mask	☐ Above USD1.5 (Above HKD12) per mask

4.13 Are you aware of products recycled from disposable masks?

☐ Yes	☐ No

Part 5. Reusable face masks

5.1Age Group

☐ Under 18	☐ 19–29	☐ 30–49
☐40–59	☐ 60 or above	

5.2 Have you used the reusable masks?

☐ Yes	☐ No

5.3 Which masks do you use the most?

☐ disposable masks	☐ reusable masks

5.4 The number of disposable masks usually worn when going out

☐ 0	☐ 1	☐ 2
☐ 3	☐ 4	

5.5 Why do you prefer using reusable masks instead of disposable masks?

☐ Free to take (CUMask from HKSAR)	☐ Good out-looking	☐ More environmental friendly
☐More protective	☐ easy to get	☐ More comfortable
☐Lower cost		

5.6 How much do you usually spend to buy a disposable mask?

☐ HKD0–HKD2	☐ HKD2–HKD5
☐ HKD5–HKD10	☐ More than HKD10

5.7 According to your answer in question 8, do you think the price is acceptable?

☐ Yes	☐ No

5.8 How often do you use reusable mask?

☐ Always	☐ Sometimes	☐ few times
☐Often		

5.9 When would you like to use reusable mask?

☐ Any situation	☐ Short Duration on street	☐ Wear both reusable mask and disposable masks at the same time

5.10 How much do you usually spend to buy a reusable mask?

☐ HKD0–HKD5	☐ HKD10–20
☐ HKD5–HKD10	☐ More than HKD20

5.11 The price of reusable masks reasonable or not.

☐ Yes	☐ No

5.12 Which type of reusable mask you would use?

☐ CUMask (Provided by HKSAR)	☐ Cloth mask	☐ Pitta Mask (Blocking dust/pollen, but not virus/bacteria)

Part 6. Self-charging face masks

6.1 Gender and age

☐ Male	☐ Female
☐ Under 20	☐ 20–35
☐ 35–50	☐ Over 50

6.2 Region

☐ People's Republic of China	☐ Hong Kong, China

6.3 What type of mask do you usually use?

☐ Single-use surgical facemask	☐ N95 facemask	☐ Self-charging facemask
☐ Cotton facemask	☐ Others	

6.4 How often do you wear a facemask?

☐ I never wear facemask	☐ Occasionally (less than or equal to 3 days a week)	☐ Wear it frequently (more than 3 days a week)

6.5 How often do you change your facemask?

☐ Within 8 hours	☐ 8 hours to 1 day	☐ 1 to 2 days
☐ More than 2 days		

6.6 Have you ever used facemasks that use electrostatic attraction (such as self-charging facemasks)?

☐ Yes	☐ No

6.7 What do you know about the advantages of facemasks using electrostatic attraction (multiple choices)?

☐ Self-charging through daily activities such as breathing and speaking	☐ Good breathability	☐ Long service life (more than 30 days)
☐ Superior virus filtering capability		

6.8 Do you think self-charging facemasks can alleviate the environmental pollution caused by single-use surgical facemasks to a certain extent?

☐ Yes	☐ No

6.9 What price would you pay for a self-charging facemask with all the above advantages?

☐ Less than HKD20 (RMB16)	☐ USD20–50 (RMB16–40)
☐ USD50–100 (RMB40–80)	☐ More than HKD100 (RMB80)

Appendix B: Online Seminar Schedule

	5th October 2023 (Thursday)		
11:45 – 12:00 HKT (GMT+8)	Welcome ceremony		
12:00 – 13:00 HKT (GMT+8)	Prof. Loh Xian Jun, Executive Director	Agency for Science, Technology and Research (Singapore)	Face Masks in the New COVID-19 Normal: Materials, Testing, and Perspectives Q&A session
13:00 – 14:00 HKT (GMT+8)	Prof. Li Wen Jung Vice President	City University of Hong Kong	A Nano-Composite Sensor Integrated AI-Mask for Tracking Multiphase Respiratory Activities Q&A session
14:00 – 15:00 HKT (GMT+8)	Dr. Yao Lei, Director	The Hong Kong Research Institute of Textiles and Apparel	Development of a Reusable and Comfort Facemask as a Barrier to Microorganisms Q&A session
15:00 – 17:00 HKT (GMT+8)	Discussion between speakers and audience		
Break			
19:00 – 20:00 HKT (GMT+8)	Dr. Jasper Fuk-Woo Chan Clinical associate professor	The University of Hong Kong	Face masks for respiratory tract viral infections: what are the evidences? Q&A session
20:00 – 21:00 HKT (GMT+8)	Dr. Nazek El-Atab Assistant Professor	King Abdullah University of Science and Technology (Saudi Arabia)	Flexible Nanoporous Template for the Design and Development of Reusable Anti-COVID-19 Hydrophobic Face Masks Q&A session
21:00 – 22:00 HKT (GMT+8)	Dr. Thanh D. Nguyen Associate Professor	University of Connecticut (United States)	Piezoelectric Nanofiber Membrane for Reusable, Stable and Highly Functional Face Mask Filter with Long-Term Biodegradability Q&A session
22:00 – 22:30 HKT (GMT+8)	Summary & Closing ceremony		

Appendix C: Online Seminar Poster