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Surveillance approaches to determine the risk, frequency and origin of SARS-CoV-2 entry into UK airports

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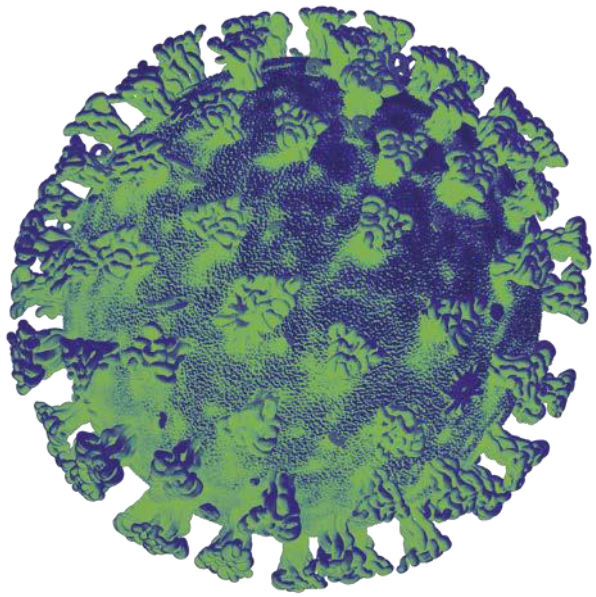

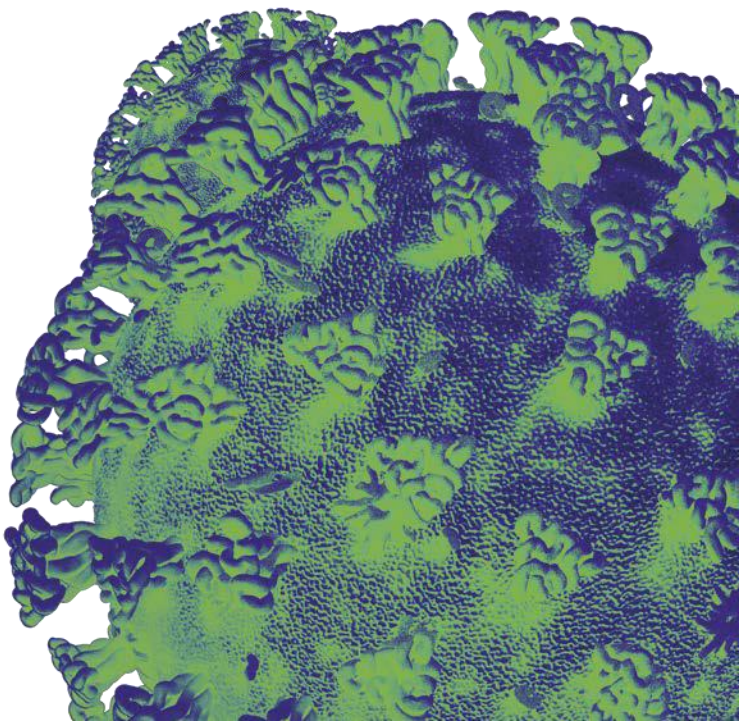

Surveillance approaches to determine the risk, frequency and origin of SARS-CoV-2 entry into UK airports

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Summary

There is now overwhelming evidence that the COVID-19 global pandemic and transboundary movement of SARS-CoV-2 was fueled by air travel. It is therefore important to better understand passenger behaviour and perceptions to COVID-19 to enable the design of effective mitigation measures to minimize further spread of the disease and the safe reopening of air routes. In this study of UK adults (*n* = 2103), we quantified (i) their knowledge of COVID-19 symptoms, (ii) the perceived health risk if they were to contract COVID-19, (iii) the likelihood that they would return to the UK if they started to exhibit COVID-19 symptoms, (iv) whether they would obey government guidelines on self-quarantining on return to the UK, (v) for those who had travelled overseas by air during the pandemic (*n* = 305), how safe they felt during the flight, (vi)

their perception of the effectiveness of face coverings, and (vii) their toilet habits during the flight to assess whether aircraft wastewater could be used as a COVID-19 surveillance tool. The survey was stratified by gender, age, social class and geographical region. Overall, we found that an individual's knowledge of the range of symptoms associated with COVID-19 was poor. Men and younger age groups (18-44) were less well informed that women and older age groups (44+). This suggests that many individuals could unknowingly return to the UK with COVID-19. We also found that a significant proportion (21%) of the population would likely travel back to the UK even if they started to express COVID-19 symptoms. Further, many individuals expressed the opinion that they would not fully comply with government self-isolation guidelines on return. Overall, males and younger ages groups had a reduced perceived personal risk from contracting COVID-19 and our results suggest that they pose a higher risk of transporting SARS-CoV-2 back to the UK. Of those who have travelled during the pandemic, most felt moderately safe whilst on the aircraft, although the effectiveness of face coverings in preventing the spread of COVID-19 on planes was perceived to be quite low. Based on individual toilet habits on planes, our results suggest that the use of wastewater for the surveillance of COVID-19 is only useful on long-haul flights. Based on this national survey of air passenger behavioural patterns and individual perceptions of COVID-19, we conclude that current government guidelines and policies are likely to be insufficient to prevent the frequent entry of SARS-CoV-2 into the UK. Our recommendation supports the imposition of stricter guidelines to ensure complete compliance with point-of-departure COVID-19 testing and stricter quarantining on arrival for UK citizens returning from overseas. In addition, we recommend that these be targeted at younger age groups where the risk of non-compliance is greatest.

1. Introduction

The importance of air travel in facilitating the long-distance spread of COVID-19 is undisputed (Linka et al., 2020; Worobey et al., 2020; Zhuang et al., 2020; Mouchtouri et al., 2020; Pavli et al., 2020). For example, it is now well established that UK citizens returning from mainland Europe (e.g. Italy, Spain and France), rather than China, were primarily responsible for introducing SARS-CoV-2 into the UK (Pybus et al., 2020). Based on sequencing it has been estimated that at least 1300 independently-introduced transmission lineages of the virus were introduced to the UK in early 2020, leading to the first wave of COVID-19 (Pybus et al., 2020). Based on this we estimate that infected passengers entering the UK represented ca. 0.02% of the 8 million passengers arriving during this period. This was, however, notably lower than the estimated 1.3% of infected international passengers that left Wuhan at the start of the pandemic and which fueled the global spread of the disease (Luo et al., 2020). At the beginning of the second COVID-19 wave in Europe, in-flight transmission of SARS-CoV-2 between passengers was also documented in a flight from Greece to Ireland, where the attack rate was 10-17% (Murphy et al., 2020). This transmission occurred despite the use of face coverings and the implementation of social distancing measures. A range of modelling and epidemiological case studies has also confirmed that one infected person on a flight could transmit the disease to other passengers throughout the plane (Hoehl et al., 2020). This is not helped by the close proximity of other passengers, intrinsic air circulation patterns and closely confined and high frequency use toilet facilities. The potential for importing and transmitting SARS-CoV-2 on aircraft mirrors the findings for other respiratory viral diseases (e.g. influenza; Gupta et al., 2012; Leitmeyer et al., 2016). In addition, the potential for transmission within crowded airport terminals has also been demonstrated for other respiratory pathogens (e.g. adenovirus; Bailey et al., 2018) suggesting that a single individual

carrying the disease may infect multiple people all travelling to different destinations.

Although closure of international flights has inevitably helped contain the spread of the disease, it has come at a substantial cost (Suau-Sanchez et al., 2020). For example, it was predicted that COVID-19 restrictions on air travel would lead to GDP losses of 2.0% and job losses of 5.0 million by the end of 2020 across Europe (Iacus et al., 2020). There is therefore an urgent drive from the travel industry to re-open international air routes. However, this must be done in a socially responsible, practical and economic way that will ensure protection of public health. Key to this is effective disease control and surveillance. This clearly requires the development of effective surveillance technologies but also necessitates a good knowledge of individual attitudes to COVID-19 and their behaviour before, during and after air travel.

Appraisal of airport entry screening measures have shown that it is highly resource demanding (Wilder-Smith et al., 2003) and often ineffectual (Mouchtouri et al., 2020). Although a range of strategies are now in place for national disease surveillance (e.g. contact tracing, self-reporting apps, targeted and untargeted swab, testing, seroprevalence), we still lack ways to reliably estimate rates of disease entry from overseas travelers. Based on the known trans-national importation of new variants of COVID-19 (e.g. import of B.1.1.248 from Brazil and B.1.351 from South Africa to the UK), it is clear that current surveillance strategies are inadequate both at the point of departure and the point of entry. This is either because (i) current technologies lack scientific credibility (e.g. thermal imaging gates), (ii) are not cost-effective for mass deployment, (iii) are subject to error (e.g. lateral flow devices), (iv) fail to capture recently acquired infections (e.g. those acquired within hours of departure), (v) are not available at the point of departure, (vi) cannot capture infections acquired during travel (e.g. in transit lounges or on the flight), or (vii) solely rely on self-reporting which fails to capture asymptomatic, pre-symptomatic, mildly symptomatic

individuals and those knowingly concealing symptoms (Samaan et al., 2004; Mitra et al., 2020). This is supported by an ECDC study which estimated that ca. 75% of infected individuals from China arrived at their destination undetected (ECDC, 2020). To help mitigate this, many countries have implemented policies of self-imposed quarantining passengers for 10-14 days upon arrival. Clearly, this relies on individual compliance if it is to be effective.

With a focus on UK air travelers and those that have flown during the pandemic, the primary aims of this study were to (i) evaluate passenger knowledge of COVID-19 symptoms, (ii) their attitudes to catching COVID-19, (iii) evaluate their likelihood of returning back to the UK if they, or a member of their family, were ill, (iv) evaluate their perceived safety during recent air travel, and (v) the likelihood that they would self-quarantine for the full period on return to the UK. Our secondary aim was to evaluate the potential for using aircraft wastewater as a mechanism for disease surveillance.

2. Materials and Methods

2.1. Study design

We commissioned the ESOMAR accredited market research company YouGov (YouGov Ltd., London, UK; Twyman, 2008) to carry out this cross-sectional survey, between the 22nd to 23rd October, 2020. Participants (n = 2103) were recruited from YouGov's online research panel (n = 800,000+ UK adults) and were eligible if they were aged 18 years or older and living in the UK. Comparisons of opt-in internet panels with traditional stratified random sample interview and random digit dial techniques conclude that the biases introduced by this methodology are small, and in general are more than offset by the much larger sample sizes the internet-based methodology permits (Hill et al., 2007). The random error on a sample of 2,000 individuals is estimated to be up to 2% (YouGov). Quota sampling was used, based on age, gender,

social grade, level of education and Government Office Region, to ensure that the sample was broadly representative of the UK general population. All participants provided sociodemographic variables and none were excluded from the subsequent analysis. Participants were invited to participate in the survey by an email with the subsequent survey conducted on-line via the YouGov data portal. Active sampling restrictions were put in place to ensure that only people contacted and registered with YouGov were allowed to participate.

2.2. Questionnaire

The survey consisted of 18 closed-ended questions, with seventeen of the questions addressing issues associated with travelling by air and 11 questions addressing specific demographic topics. The questionnaire used in this study was designed by the research team, consisting of environmental microbiologists, public health specialists and social scientists, based on the study objectives and incorporating information from previous studies on same topic. The draft questionnaire was then tested on an expert panel, a panel of non-experts, a local ethics committee and finally refined by YouGov prior to deployment. First, perceived risks, concerns, and subjective knowledge of COVID-19 symptoms were measured using 16 options that included 14 actual symptoms and 2 which were not. Other questions about perception and risk were measured by statements with a 5-point Likert scale (e.g. strongly disagree to strongly agree).

2.3. Personal characteristics

We asked participants to report their age, gender, social grade, employment status, highest educational or professional qualification and marital status. We also asked whether there was a child in their household, what social media/messaging

platforms they had used in the last month (Facebook, Twitter, LinkedIn, Instagram, Snapchat WhatsApp, and Skype), whether they had travelled abroad by plane since the start of the COVID-19 pandemic and whether they had ever tested positive for COVID-19. Participants were asked for their postcode to determine indices of multiple deprivation (IMD) and their social grade.

2.4. Ethics

Ethical approval for this study was granted by the Bangor University College of Environmental Sciences and Engineering Ethics Committee (Approval Number: COESE2020EG01A).

2.5. Analysis

Any percentages calculated on bases fewer than 50 respondents (<2.3% of the total) were included with the caveat that they may not represent a true cross-section of the target population and should be used as indicative only. Comparisons between groups was made using chi-squared tests using $P < 0.05$ as the cut-off for statistical significance.

3. Results

3.1. Recognition of COVID-19 symptoms

Overall, there was good knowledge of the main symptoms of COVID-19 (e.g. fever, cough, shortness of breath) among the respondents (Fig. 1A). In contrast, other symptoms associated with the onset of COVID-19 were not recognized by the majority of respondents (e.g. skin rash, muscle and body aches, diarrhea, headache, nausea and vomiting). The two symptoms not typically associated with COVID-19 (nerve pain and constipation) were only highlighted by ca. 2% of respondents. For the 10

symptoms where the response rate was greater than 10% (i.e. $n > 250$), female respondents were better able to recognize the actual COVID-19 symptoms by 25 ± 9% in comparison to the male cohort ($P < 0.001$). In addition, for the same top 10 ranked symptoms, 9 showed an increased recognition of symptoms with age (Fig. 1B; $P < 0.05$). When comparing the cohort with least risk to developing severe COVID-19 symptoms (ages 18-24) to those in the older, more susceptible cohort (age 55+), the older generation were on average 66 ± 29% better at recognizing the symptoms ($P < 0.001$). No significant effect of social class (A, B, C1 versus C2, D, E; see Supplementary Information Table S1 for details) on COVID-19 symptom recognition was observed ($P = 0.65$). The responses of adults with and without children was also very similar, although those with children (<18 years in age) were on average 9 ± 3% better at recognizing the symptoms. The variation in COVID-19 symptom recognition was not associated with media platforms used by the respondents in the last month (all $P > 0.05$).

The actual reported symptoms of COVID-19 by individuals in the UK is shown in Figure 2. Overall, there is a partial agreement about the most common perceived (Fig. 1) and actual (Fig. 2) COVID-19 symptoms, however, there are notable exceptions including vomiting, abdominal pain, diarrhea and fatigue which were not widely recognized as symptoms by the majority of individuals, particularly men and the younger age groups.

3.2. Perception of the risk of catching COVID-19

Of those who answered ($n = 2103$), 17% of respondents were not worried about catching COVID-19, 56% expressed some concern and 27% exhibited strong concern about catching the disease (Fig. 3). This was not greatly affected by gender, social grade, however, greater concern was expressed in older people relative to those in

the youngest age group (34 vs. 13%) and also by parents with children relative to those without (31 vs. 22%). Of those surveyed, 1.3% (*n* = 27) had previously tested positive for COVID-19, while a further 10.3% believed they had contracted COVID-19 but had never been formally tested, with the remainder not knowingly having contracted the disease. The number of confirmed or suspected positive cases was not associated with differences in gender, age, social class or the presence of children in the household.

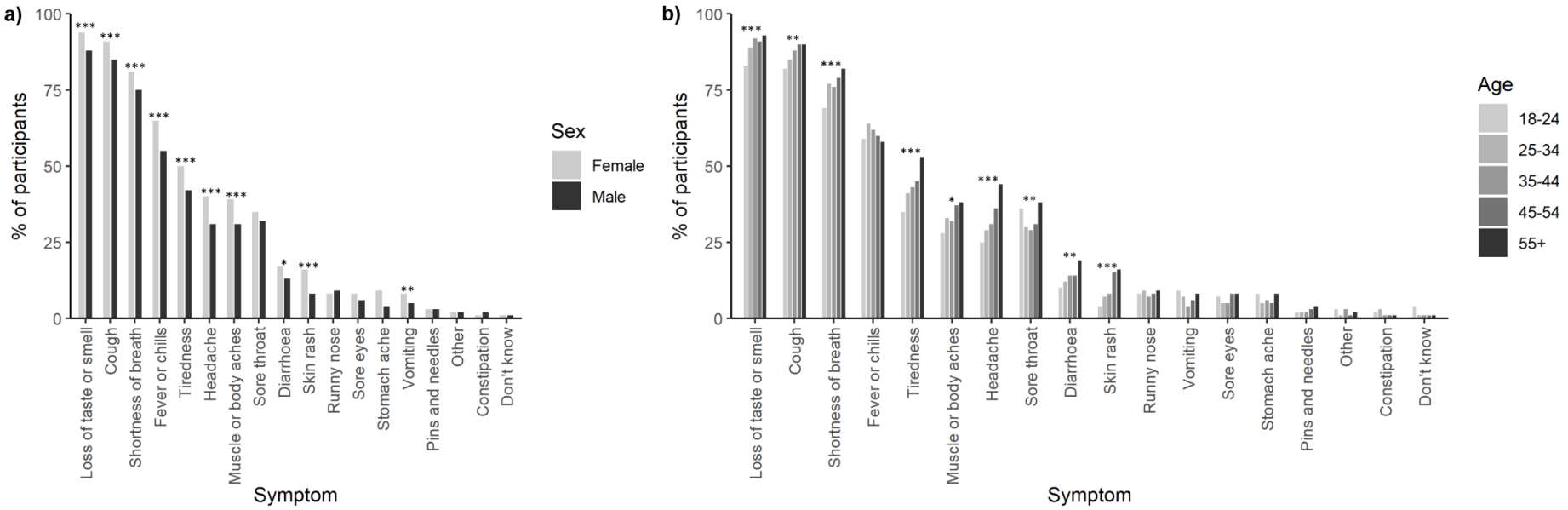

Fig. 1. Evaluation of the knowledge of individuals about different symptoms of COVID-19, stratified by either (A) gender, or (B) age (n = 2103). *, **, and *** represent significant differences between the gender or age categories for a particular symptom at the $P < 0.05$, $P < 0.01$ or $P < 0.001$ level, respectively.

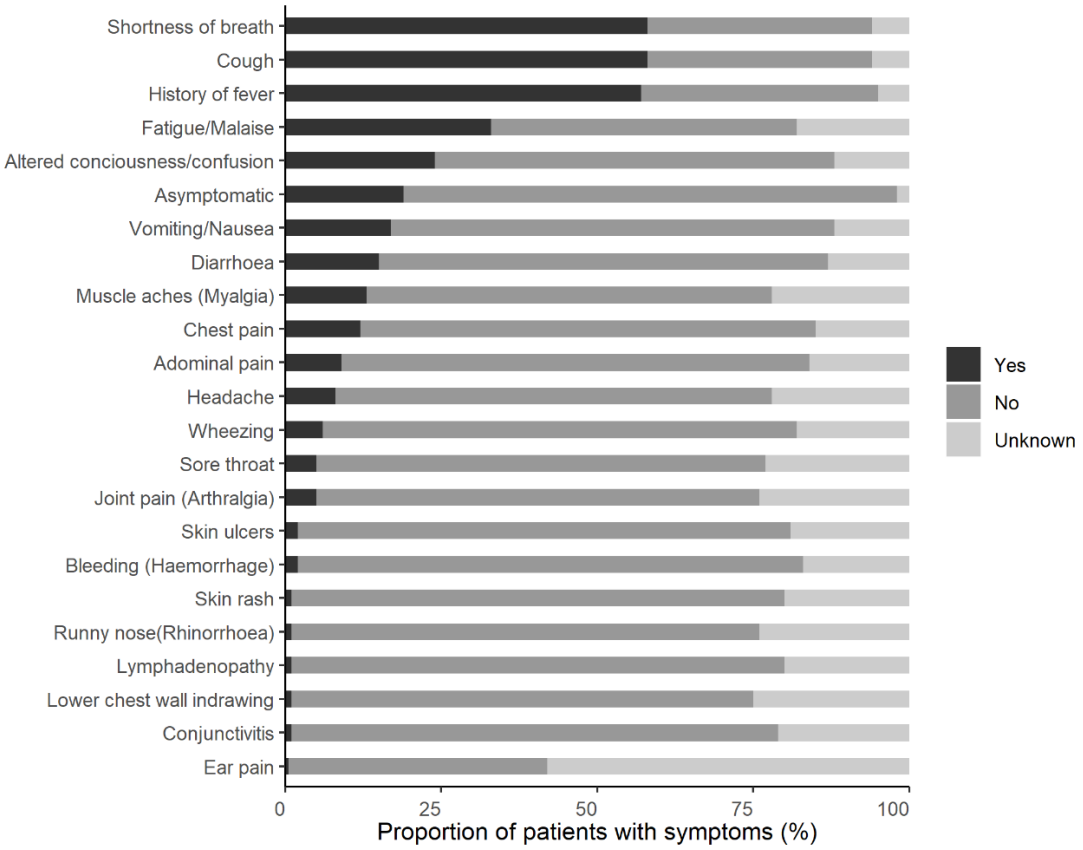

Fig. 2. Actual symptoms of COVID-19 experienced by infected individuals in the UK. (*incl. source and need to match categories to those in Fig. 1*).

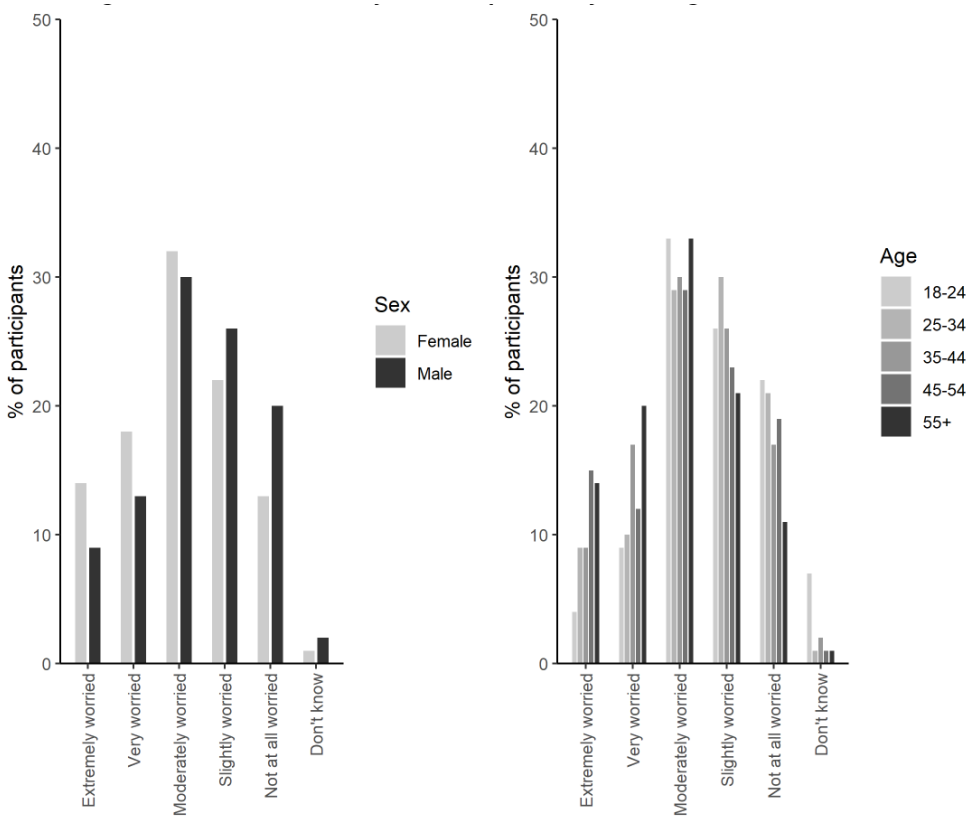

Fig. 3. Evaluation of an individual's perceived health risk from catching COVID-19, stratified by either (A) gender, or (B) age (*n* = 2103). *, **, and *** represent significant differences between the gender or age categories for a particular symptom at the *P* < 0.05, *P* < 0.01 or *P* < 0.001 level, respectively (*add stats*).

3.3. Perceived likelihood of flying back to the UK while showing signs of illness and the likelihood of quarantining (self-isolation) upon landing in the UK

When asked about their previous experience of returning back to the UK on an international flight, 23% of respondents indicated that they had previously boarded a flight while feeling ill (e.g. feeling sick, diarrhea, headache etc; Fig. 4). Although not affected by social grade or gender, a greater proportion of the younger age groups (ages 18-44, *n* = 833) had travelled while ill in comparison to those in the older age groups (ages 44+, *n* = 1076). Travelling while ill was also more frequent in households without children (29 vs 18%).

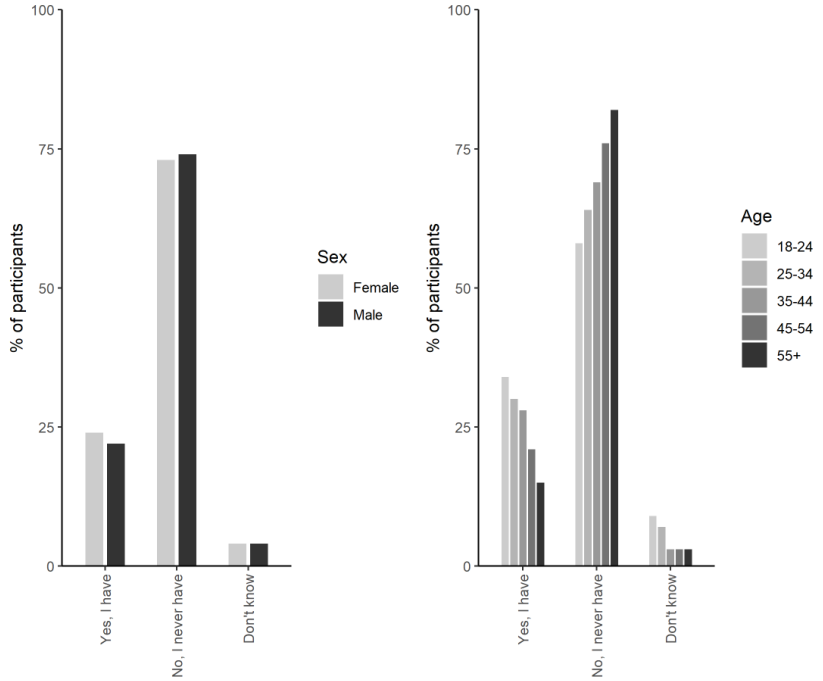

Fig. 4. Evaluation of the number of individuals who have previously returned back to the UK on a flight while showing signs of illness (non-COVID-19 related), stratified by either (A) gender, or (B) age (n = 2103). *, **, and *** represent significant differences between the gender or age categories for a particular symptom at the $P < 0.05$, $P < 0.01$ or $P < 0.001$ level, respectively (*add stats*).

In the hypothetical situation that an individual started to express potential symptoms of COVID-19, we asked their likelihood of returning on their scheduled flight. Overall, 21% said they would, 52% said they would not and 27% of individuals indicated that they were unsure (Fig. 5a). Overall, slightly more men said they would potentially travel back with COVID-19 symptoms relative to women (24 vs. 18%). A return to the UK while expressing COVID-19 symptoms was also higher in the younger age groups (ages 18-44) relative to those in the older age groups (ages 44+) while social grade and the presence of children in households proved not to be significant.

When individuals were asked whether they would fly home with another person who might by exhibiting potential COVID-19 symptoms (even though they themselves were not), the responses were generally similar to if they had symptoms with 27%

saying they would still travel home, while 45% would not and 28% of individuals remained unsure (Fig. 5b).

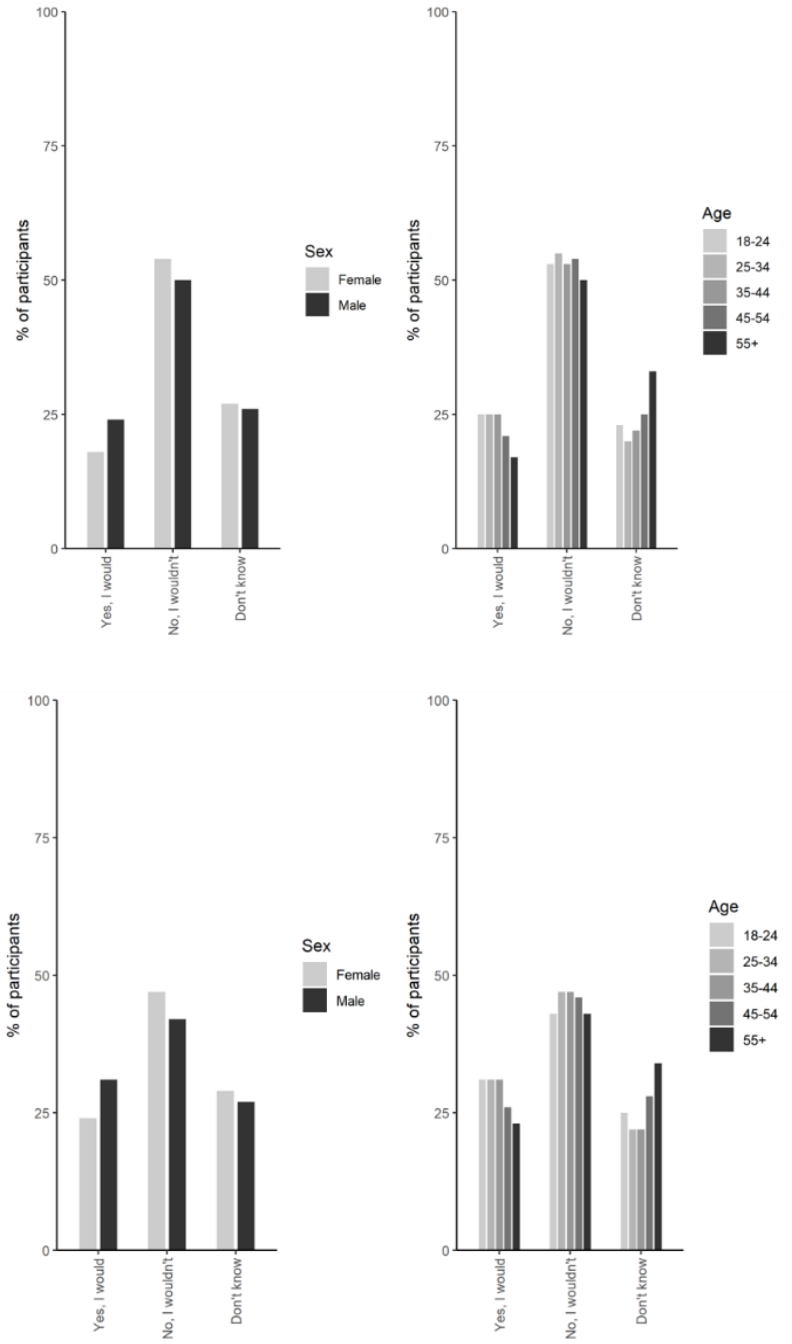

Fig. 5. Evaluation of the number of individuals who would travel back to the UK if they started to show symptoms of COVID-19 (A, top panel), or a member of their family or party was starting to show symptoms of COVID-19 (B, lower panel), stratified by either (A) gender, or (B) age (n = 2103). *, **, and *** represent significant differences between the gender or age categories for a particular symptom at the $P < 0.05$, $P < 0.01$ or $P < 0.001$ level, respectively (*add stats*).

To better understand the likelihood that an individual would self-quarantine following return from a country on the UK government's quarantine list, 83% of individuals reported that they would probably quarantine for the full 10-day period, while 10.2% said they would not (Fig. 6). These responses were stratified by age and gender, but not social grade or the presence of children in the household. Females were more likely to obey government guidance than men. The younger generation were also more likely to break the self-isolate guidance (17%) relative to the older population (6%).

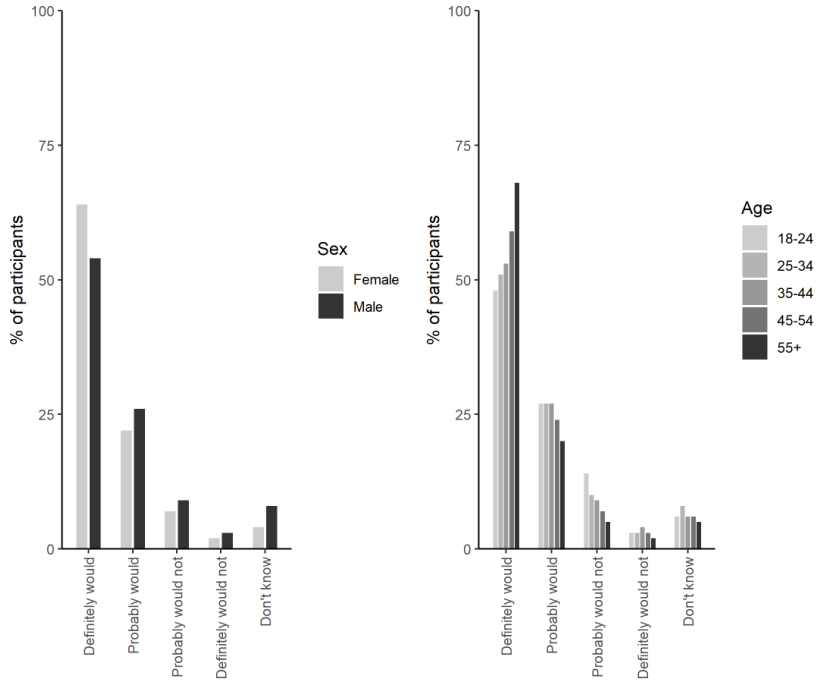

Fig. 6. Evaluation of the number of individuals who said that they would not self-isolate for the full 10 day period on return to the UK from a country included on the UK's quarantine, stratified by either (A) gender, or (B) age (n = 2103). *, **, and *** represent significant differences between the gender or age categories for a particular symptom at the $P < 0.05$, $P < 0.01$ or $P < 0.001$ level, respectively (*add stats*).

3.4. Personal safety while flying during the COVID-19 pandemic

Of the total number of respondents polled, 15.2% (n = 305) of them indicated

they had flown since the start of the COVID-19 pandemic. The greatest numbers of flights were taken by the youngest age group (age 18-24) and the more affluent social grades (A, B, C1). Of these 47% expressed that they felt safe from potentially catching COVID-19 during the flight while 13% indicated that they did not (Fig. 7). These levels were not affected by any of the demographic categories analyzed here.

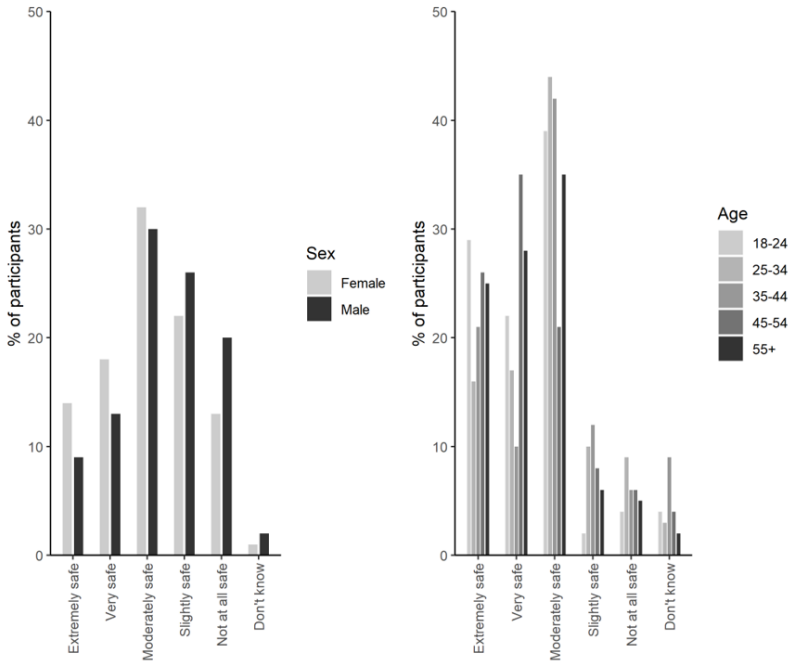

Fig. 7. Evaluation of how safe passengers felt from the risk of contracting COVID-19 whilst on a flight returning to the UK since the start of the COVID-19 pandemic, stratified by either (A) gender, or (B) age (n = 305). *, **, and *** represent significant differences between the gender or age categories for a particular symptom at the $P < 0.05$, $P < 0.01$ or $P < 0.001$ level, respectively (*add stats*).

When asked about the effectiveness of containing the spread of COVID-19 on the flight with face coverings, the respondents were equally split with 32% reporting that they were effective, 36% only partially effective, and 32% reporting that they were ineffective (Fig. 8). These views were not strongly influenced by any of the demographic categories analyzed here. Further analysis revealed that 93% of individuals would wear face masks on a plane, but of these 31% would only do it if it

was mandatory (data not presented). These proportions were not influenced by social grade or gender, however, the over 55 age group were more likely to wear a face mask whether it was mandatory or not (72%) relative to the other age groups (57 ± 2%).

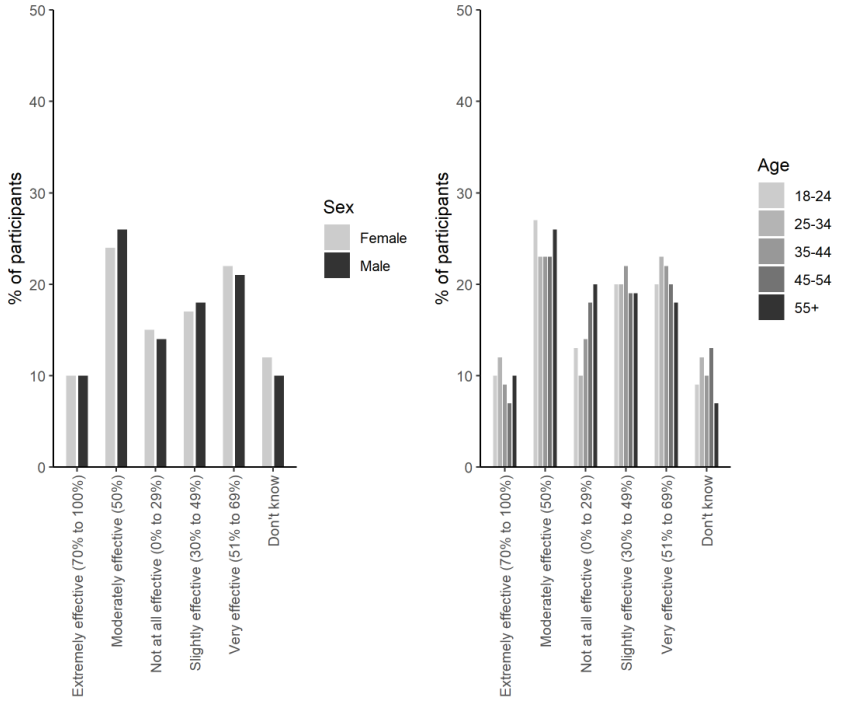

Fig. 8. Evaluation of individuals' perceptions on the effectiveness of face coverings at preventing the risk of spreading COVID-19 on a flight returning to the UK, stratified by either (A) gender, or (B) age (*n* = 2103). *, **, and *** represent significant differences between the gender or age categories for a particular symptom at the $P < 0.05$, $P < 0.01$ or $P < 0.001$ level, respectively (*add stats*).

3.5. Toilet and personal hygiene behaviour on aircraft

Toilets on aircraft are confined spaces with high frequency occupancy. When asked if they would wash their hands following recommended guidelines for COVID-19 control (e.g. 20 seconds with soap) after visiting the toilet, 84% of respondents suggested that they would, while 14% suggested they would not. Generally, compliance with hand washing was greater in women and those in older age groups (Fig. 9).

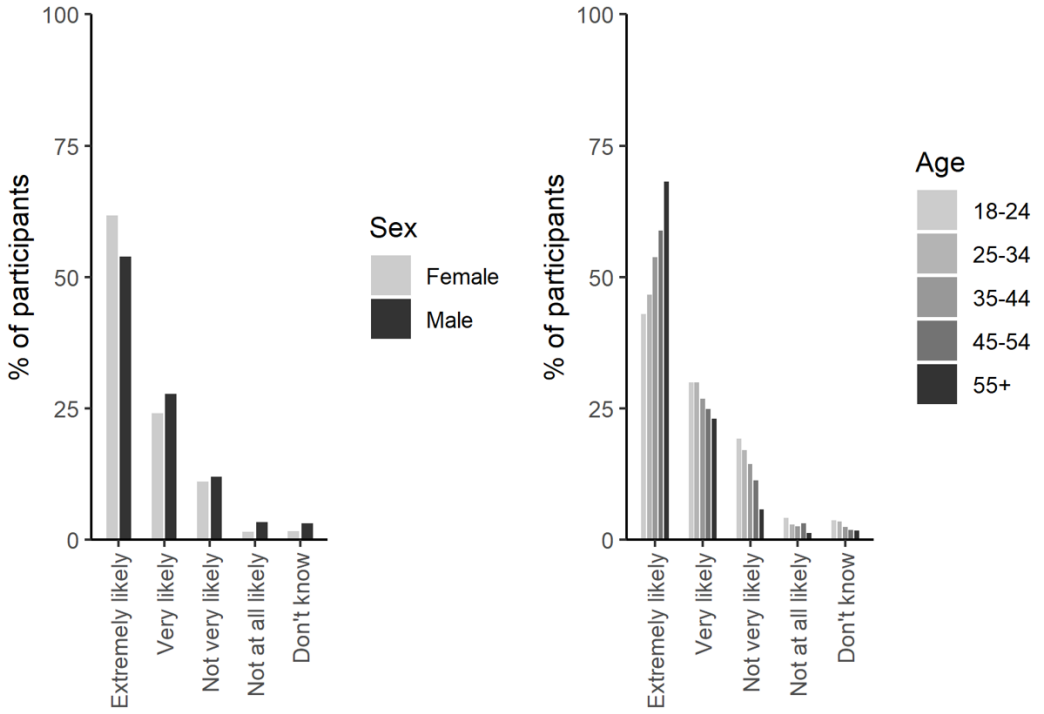

Fig. 9. Participant responses (*n* = 2103) stratified by gender and age evaluating the likelihood that they would wash their hands thoroughly (with soap, 20 secs) within an aircraft toilet setting.

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As approximately 30-40% of COVID-19 cases shed SARS-CoV-2 in fecal material (REF?), we asked individuals about the likelihood that they would defecate either before, during or after a flight. This information is useful to determine whether the analysis of aircraft wastewater can be used as a mass surveillance tool for evaluating the potential that infected individuals have entered the UK from overseas. On short haul flights only 8% of individuals said they would defecate during the flight, while on long haul flights this increased to 32% (Fig. 10). In comparison, 39% indicated that they were likely to defecate before boarding the plane while 23% indicated that they would defecate upon landing (Fig. 11).

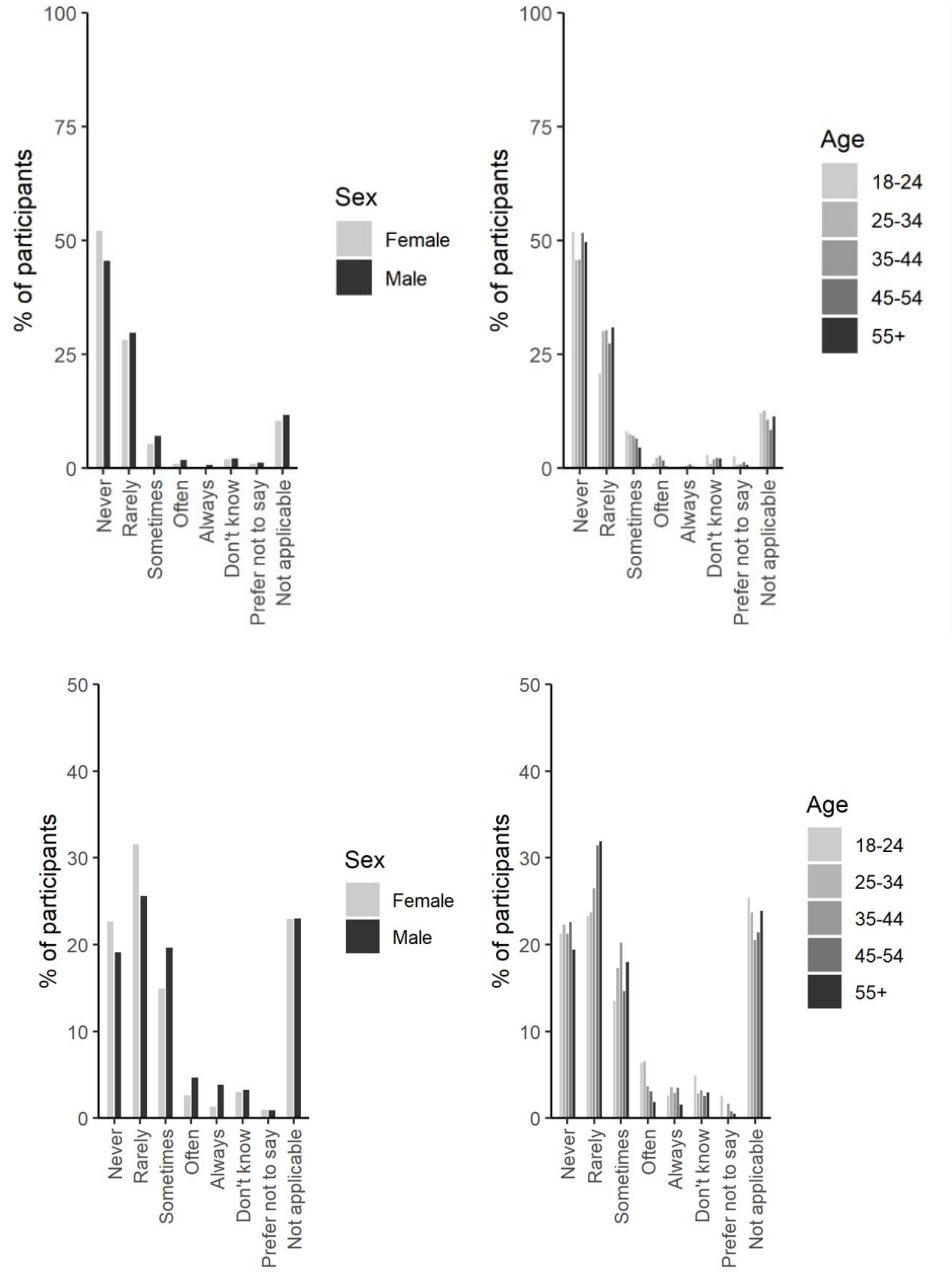

Fig. 10. Evaluation of the likelihood that individuals would use the aircraft toilet to defecate on either a short-haul flight (A, upper panels) or long-haul flights (B, lower panels), stratified by either (A) gender, or (B) age (*n* = 2103). *, **, and *** represent significant differences between the gender or age categories for a particular symptom at the $P < 0.05$, $P < 0.01$ or $P < 0.001$ level, respectively (*add stats*).

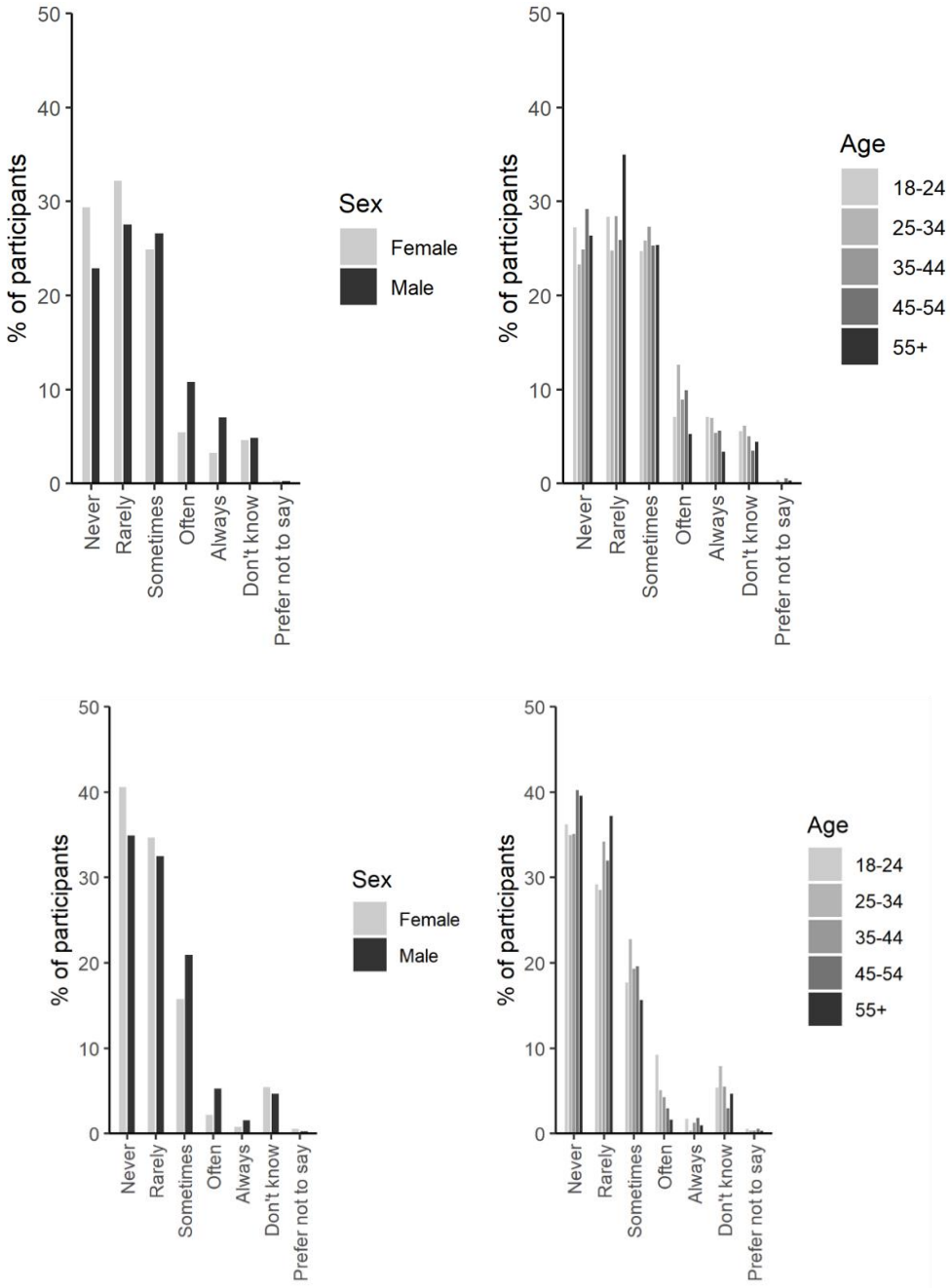

Fig. 11. Evaluation of the likelihood that individuals would use the airport terminal toilets to defecate either before boarding the plane (A, upper panels) or upon landing in the UK (B, lower panels), stratified by either (A) gender, or (B) age (*n* = 2103). *, **, and *** represent significant differences between the gender or age categories for a particular symptom at the $P < 0.05$, $P < 0.01$ or $P < 0.001$ level, respectively (*add stats*).

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Table 1. Respondent key demographic variables.

	Number	% of total
Age		
18–24	210	**To complete**
25–34	311	
35–44	403	
45-54	365	
55+	814	
Gender		
Male	1008	
Female	1095	
Social grade		
A, B, C1	1230	
C2, D, E	873	
Marital status		
Married	931	
Living as married	257	
Separated/divorced	198	
Widowed	89	
Never married	616	
Parent/guardian		
Yes	1207	
No	896	
Social media		
Facebook	1478	
Twitter	756	
LinkedIn	373	
Instagram	774	
Snapchat	317	
Facebook Messenger	1337	
WhatsApp	1426	
Skype	215	

Supplementary Information

Approximated Social Grade with its six categories A, B, C1, C2, D and E is a socio-economic classification produced by the ONS (UK Office for National Statistics) by applying an algorithm developed by members of the MRS Census & Geodemographics Group. It applies to every Household Reference Persons (HRP) aged 16 to 64. Social Grade based on the census 2011 data is available for all four UK countries (England, Wales, Northern Ireland and Scotland).

Table S1. Social grade categories used in the questionnaire.

Social grade	Description	% of UK population
AB	Higher & intermediate managerial, administrative, professional occupations	22.17
C1	Supervisory, clerical & junior managerial, administrative, professional occupations	30.84
C2	Skilled manual occupations	20.94
DE	Semi-skilled & unskilled manual occupations, Unemployed and lowest grade occupations	26.05