SARS-CoV-2 vaccination and chemosensory dysfunction after COVID-19

Running title:
COVID-19 vaccination and chemosensory dysfunction

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ABSTRACT

Background: Olfactory and taste dysfunction is a common symptom of COVID-19 and post-acute COVID-19 syndrome. While COVID-19 vaccines have been suggested to affect chemosensory function both positively and negatively, data remained limited. This global survey study aimed to assess post-vaccination changes in chemosensory perception among individuals whose chemosensory function was impaired by COVID-19.

Methods: A multilingual online survey was distributed via convenience sampling (e.g., social media, email invitations to prior study participants). Between May 2022 and August 2023, 2,955 responses were received. Participants reported chemosensory outcomes and side effects for each vaccine dose. Data were analyzed by vaccine brand, dose number, and pre-existing symptoms.

Results: Across vaccine doses, 90-97% of participants reported no change in general smell or taste, while 3-8% reported improvement and 2-7% reported worsening. Improvement rates were higher for qualitative symptoms including parosmia (11-18%), phantosmia (20-29%), and taste distortion (12-21%). Among all brands, Moderna's first dose was associated with the highest improvement rate for parosmia (24.5%). Side effects varied by vaccine type and were more frequent among individuals reporting worsened chemosensory symptoms.

Conclusions: COVID-19 vaccination may influence qualitative chemosensory symptoms in select individuals, with brand-specific differences observed. These findings are exploratory and should be interpreted with caution due to self-reported data, potential selection bias, and the possibility of natural recovery. Future controlled studies with objective assessments are needed to confirm these observations and clarify underlying mechanisms.

Keywords: COVID-19, vaccines, olfactory disorders, parosmia, phantosmia, post-acute COVID-19 syndrome

INTRODUCTION

Following the outbreak of COVID-19 (Coronavirus disease 2019) caused by SARS-CoV-2, extensive effort was put into developing a vaccine. In less than one year, the first vaccines for COVID-19 were developed (see reviews[1–3]) and became available. Currently, four different vaccine categories are available. They differ in the mechanism of antigen delivery: mRNA vaccines, adenovirus vector vaccines, inactivated virus vaccines, and recombinant protein vaccines (see reviews[1–3] as well as an overview by the World Health Organization (WHO)[4]).

Many studies have described the symptoms of COVID-19 symptoms since the pandemic's onset (e.g., see these reviews[5,6]). Acute COVID-19 can manifest with fever, cough, fatigue, shortness of breath, gastrointestinal symptoms, neurological symptoms, and chemosensory dysfunction, although asymptomatic infections have been reported as well[7,8]. Symptom recovery trajectories vary between individuals[9–12], with symptoms persisting for 3 months post-infection being referred to as post-covid syndrome, post-acute sequelae of COVID-19, or Long COVID[13,14], and later becoming a Medical Subject Headings (MeSH) term "Post-acute COVID-19 syndrome" (PCS). Due to the non-specific nature of PCS symptoms, prevalence estimates of PCS vary between studies, but recent data suggest it may affect as much as 45% of patients[13,14].

Chemosensory dysfunction is a known symptom of COVID-19 and PCS, which includes impaired or distorted smell, taste, or chemesthetic perception[15–20]. Although chemosensory dysfunctions were previously observed with other viral infections of the upper respiratory system, their occurrence was relatively rare compared to COVID-19[21], in which up to 77 % of COVID-19 patients reported smell dysfunction and 44 % reported taste dysfunction[15,20,22–24].

Soon after vaccines became available, case reports and cohort studies have suggested that vaccination could affect chemosensory function, both positively and negatively. A U.S.-based study using electronic medical records from >96 million individuals reported an incidence of disturbance of smell and/or taste of 0.003% and 0.009% after the first COVID-19 vaccination and after the first booster, respectively[25]. Another UK-based cohort study focused on individuals experiencing PCS reported decreasing odds of loss

of smell (-12.5%) and loss of taste (-9.2%) after receiving adenovirus vector or mRNA vaccines[26]. Temporary olfactory dysfunction after vaccination has been reported in isolated cases as well[27–29]. While different vaccine types and brands have been associated with different side effects[30], the relationship between COVID-19 vaccines and changes in chemosensory perception has not been systematically and appropriately explored.

To fill this gap, we conducted a large global online survey to investigate the relationship between COVID-19 vaccination and PCS with a focus on within-participant changes in chemosensory perception (*i.e.*, smell, taste, chemesthesis). We provide evidence for post-vaccination changes in distorted smell and taste as well as differences in PCS linked to vaccine types and brands.

MATERIALS AND METHODS

Survey design

Participants reported the date and brand of the vaccine received and if they experienced any side effects. If their answer to the latter question was ‘yes’, they could select symptoms from a list (*i.e.*, fever, headache, chills, diarrhea, vomit, stomach ache, joint ache, cough, sore throat, shortness of breath, muscle soreness, lightheadedness, dizziness, nausea, fatigue, nasal congestion, burning nose, heart problems, sleep disturbances, blood clots, skin rash, menstrual changes, brain fog, and others) and report the duration for the side effects. As our survey focused on the chemical senses, we asked questions on the influences of vaccination on the senses of smell, taste, and chemesthesis. We asked participants’ pre-vaccination status of chemical senses, whether chemosensory dysfunction had improved, worsened, or remained unchanged after vaccination, when the changes started, and the duration of the changes. We further asked if they experienced parosmia, phantosmia, and distorted taste. Participants answered the questions for each dose of vaccine received.

The survey was deployed in English, Chinese (traditional and simplified), French, German, Italian, Japanese, Persian, Russian, and Spanish via the online platform Qualtrics hosted at Indiana University (see **Supplementary Materials** for the full survey in English). The study was approved by the Global Consortium of Chemosensory Research (GCCR) Study Selection Team (ID: NDS006), the Institute Review Board of

Indiana University (Protocol #: 15050), the Human Research Ethics Committee of the University of Queensland (Project ID: 2022/HE000839), and the Bioethics Committee at the A.N. Severtsov Institute of Ecology & Evolution of Russian Academy of Sciences (Protocol #.2022-63). It was pre-registered on the Open Science Framework (OSF)[31].

Data collection and preprocessing

Our online crowdsourced survey was distributed via social media, personal communication, GCCR newsletters, and emails sent to participants of prior GCCR studies[15,16] who consented to be recontacted. A total of 2,955 responses were received between May 2022 and August 2023. Open-text data collected from non-English surveys were translated into English and then merged for analysis. The data were preprocessed according to the pre-registered exclusion criteria. A total of 1,602 respondents were excluded because they did not review all questions before exiting the survey (n = 1,066), reported pre-existing health conditions (n = 228), did not receive a COVID-19 vaccine (n = 206), were pregnant after the outbreak of COVID (a known modulator of chemosensory ability[32,33], n = 69) or younger than 18 years old (n = 33) (**Supplementary Figure 1**). Participants with pre-existing conditions were those who selected any of the following: “Neurological pathologies”, “Psychiatric pathologies”, “Head and neck trauma”, “Nasal sinus surgery”, “Head and neck radiation”, and “Impaired smell and taste perception” to the question “*Do you have below pre-existing conditions before COVID and/or before vaccination?*” We also excluded one participant who did not follow study instructions and provided information irrelevant to the study. The final sample of 1,352 participants was included in the analyses. Participants were required to answer questions related to vaccination status but others were optional. This resulted in varying response numbers per question.

Data analysis

To characterize our sample, we compiled demographic data on age, sex, country of origin, vaccination status (*i.e.*, number of vaccination doses and boosters), brand of vaccine in terms of counts per category and percentages, and pre-vaccination chemosensory status, *i.e.*, whether chemosensory perception was affected by COVID-19 before vaccination. Different vaccine brands were grouped into four types: mRNA vaccines, adenovirus vector vaccines, inactivated virus vaccines, and recombinant protein vaccines (See **Supplementary Note**).

To determine post-vaccination chemosensory changes, we first categorized participants by whether their pre-vaccination chemosensory perception was impaired due to COVID-19. Participants with pre-vaccination impairments included those who reported COVID-19-induced olfactory or taste loss and were not fully recovered, and those who had parosmia, phantosmia or distorted taste before vaccination. We summarized participants' self-reports of improvement, worsening, or no change in general sense of smell, general sense of taste, parosmia, phantosmia, distorted taste and chemesthesis. We also reported the time of onset and duration of changes in smell and taste. Data were pooled by vaccine dose. We compared post-vaccination changes in smell and taste between participants with and without pre-existing chemosensory dysfunction using Fisher's exact test. We tested if proportions of post-vaccination improvement or worsening in chemical senses were similar across vaccine brands using Fisher's test of homogeneity, followed by pairwise comparisons between brands. An α level of 0.05 was selected as a significance criterion. P-values adjusted for multiple comparisons were calculated using Holm method. We also performed binomial tests to compare percent improvement versus percent worsening for each vaccine brand and reported the two-sided p-values. Lastly, to assess whether self-reported changes in chemosensory perception were affected by recall bias, we compared mean differences in follow-up durations, i.e., time differences between the survey day and the vaccination day, between groups of participants defined by post-vaccination changes in chemosensory perception using one-way analysis of variance (ANOVA).

The frequency of each COVID-19 vaccine side effect was first summarized by the dose of the vaccine received. Then, we investigated vaccine type-specific side effects by calculating the incidence rate (proportion) of a side effect across the first three doses of vaccines of the same type. Within each vaccine type, we compared the incidence rate of a side effect between doses by means of the k-proportions test with the Marascuilo Procedure. Lastly, we compared the number of side effects between individuals grouped by their post-vaccination changes in smell and taste using one-way ANOVA and pairwise t-tests.

The k-proportions test was performed using XLSTAT (version 2021.1.1), and all other

analyses were performed in R (version 4.3.0) and RStudio (version 2023.03.0 Build 386).

RESULTS

Sample characteristics

This study included 1,352 participants from 52 countries, as reported in **Supplementary Table 1**. Participants represented six age groups: 5.11% of participants were 18 - 24 years old, 22.09% were 25 - 34, 23.94% were 35 - 44, 25.57% were 45 - 54, 16.31% were 55 - 64, and 6.97% were more than 65 years old. Nearly half of the participants identified as cis women (46.99 %), followed by "Not specified" (*i.e.*, gender not disclosed; 35.54%) and cis men (18.09%); four participants identified as genderqueer or non-binary and one as trans man (**Supplementary Figure 2**). Abnormal chemosensory perception due to COVID-19 was reported in 49% of the participants pre-vaccination, of which 69% reported impairments of both smell and taste, and the majority of the remaining participants reported solely smell impairment (**Supplementary Figure 3**).

Approximately half of the participants received two vaccine doses with one booster (46.1%), 28.2% received two doses with two boosters, 20% received two doses, and 5.8% received only one dose (see **Figure 1A** for the country-specific vaccination status). Among the 1,200 participants who received at least two doses, 44.2% (n = 531) received the Pfizer-BioNTech vaccine as the first two doses, which was the most frequent choice in most countries except Russia, Kazakhstan, Iran, the UK, and Switzerland, where the most common two doses were Sputnik V, Sinopharm, Astra-Zeneca or Moderna (**Figure 1B**). Among the 824 participants who received at least two doses and one booster, Pfizer-BioNTech double doses were most often combined with a booster from the same brand (n = 276, 33.5%) or with a booster from Moderna (n = 109, 13.2%). The third most common combination was two doses of Sputnik V plus a booster of Sputnik Light (n = 59, 7.2%, **Supplementary Table 2**).

Changes in chemosensory perception

Of all participants with pre-existing chemosensory dysfunction due to COVID-19, approximately 90% reported no changes in the corresponding modality after vaccination. Depending on the number of doses, 3-8% reported an improvement, and 2-7% a worsening in smell or taste perception (**Figure 2**). Among participants without pre-

existing chemosensory dysfunction due to COVID-19, 97% or more reported no changes in any chemosensory modality after vaccination (**Supplementary Figure 4**; **Supplementary Table 3**). Notably, there was no difference in the time between the first dose of vaccination and the survey time across individuals who reported an improvement, worsening, or no changes (**Supplementary Table 4**). Two-thirds of these reported changes started the day after vaccination, and the changes lasted for longer than one month for most participants. Only 1% reported post-vaccination changes in chemesthesis (**Supplementary Tables 5 and 6**).

Post-vaccination changes in smell differed between brands of vaccines, with the proportion of improvements after the first dose being the highest for Moderna (9.6%, 95% CI [4.4, 14.8]) and the lowest for Sputnik V (0.8%, 95% CI [-0.3, 1.9]); the proportion of worsening was lowest for Pfizer-BioNTech (1.3%, 95% CI [0.4, 2.3]) and highest for Sputnik V (4.5%, 95% CI [1.9, 7.1]). A similar pattern was observed after two doses of the same vaccines (**Table 1**). Post-vaccination changes in taste did not vary significantly between vaccine brands (**Supplementary Table 7**).

Post-vaccination changes were more pronounced in participants with specific pre-existing chemosensory distortions, such as parosmia, phantosmia, and distorted taste. The majority of changes, particularly in phantosmia and parosmia, were positive. Depending on the number of doses, 11-18% reported improvements of parosmia, 20-29% of phantosmia, and 12-21% of taste distortion (**Figure 3**). In contrast, only 3% or less reported a worsening of these conditions.

When comparing post-vaccination improvements in parosmia across vaccine brands, Moderna had the highest portion (24.5%, 95% CI [12.9, 36.1]) and Sputnik V had the lowest (6.7%, 95% CI [-0.6, 14.0]) after the first dose (**Table 2**). As for improvement for phantosmia, Moderna had the highest (34.4%, 95% CI [17.9, 50.8]) and Pfizer-BioNTech had the lowest (17.1%, 95% CI [11.1, 23.1]) (**Table 3**). Regarding post-vaccination changes in distorted taste, Sputnik showed the highest proportion of both improvements (20.0%, 95% CI [6.7, 33.3]) and worsening (8.6%, 95% CI [-0.7, 17.8]) (**Supplementary Table 8**).

Side effects of vaccination

Amongst over 7,000 self-reported instances of adverse side effects of vaccination, the most common six symptoms were fatigue (incidence rate of 34.6% after first dose), headache (32.6%), fever (32.0%), muscle pain (29.0%), chills (25.2%), and joint pain (22.1%). Other side effects included menstrual changes (10% among cis women after the first dose), brain fog (6%), and sleep disturbance (5%) (**Supplementary Figure 5**; **Supplementary Table 9**).

While the incidence rate of side effects tended to decrease with each subsequent dose, there were differences between the types of vaccines. Between individuals who received the same type of vaccine for the first three doses (*i.e.*, two doses and one booster), the mRNA vaccine group (n = 320) showed no differences in incidence rates for the six most common side effects across three doses ($p > 0.05$). In contrast, a significant decreasing incidence rates were observed for fever and chill in the adenovirus vector vaccine group (n = 80) and headache in the inactivated virus vaccine group (n = 51) ($p < 0.05$) (**Supplementary Figure 6; Supplementary Tables 10 and 11**).

Lastly, we compared the number of side effects between individuals grouped by their post-vaccination changes in smell and taste. The number of side effects in the worsening group was significantly higher than in the improvement and no-change groups for both olfactory and gustatory modalities (**Supplementary Figure 7**; **Supplementary Table 12**).

DISCUSSION

Among individuals whose chemosensory perception was impaired by COVID-19, post-vaccination changes were the most prominent in smell disorders, with over 20% and 11% of the affected individuals reporting an improvement in phantosmia and parosmia, respectively. Brand-stratified analyses showed a greater improvement of parosmia from Moderna compared to other brands, such as Pfizer-BioNTech, Astra-Zeneca, and Sputnik V. As for phantosmia, Moderna and Sputnik V both had the highest proportion of improvement and worsening. While these results could have potential application for personalized treatment, the sample sizes for the brand-stratified analyses were small, and there was no objective testing of smell and taste; hence, future investigation to replicate our findings is warranted.

More than 90% of individuals with pre-existing impaired taste and smell perception due to COVID-19 in this study reported no changes in general smell or taste after COVID-19 vaccination. Nevertheless, our results support findings from previous reports showing that COVID-19 vaccines can both improve and exacerbate chemosensory perception issues [27–29,26] despite low frequencies. This suggests that while COVID-19 vaccines could be investigated as a potential treatment for parosmia and phantosmia, their effects on treating loss of smell and taste might be minimal.

The frequencies of side effects reported in the present study decreased with the vaccine doses for most types of vaccine except for mRNA vaccines, with the side effects being the strongest after the second dose. In addition to common side effects, menstrual cycle changes were reported in more than 8% of female participants after each of the first three doses of the vaccine. A recent report suggested that COVID-19 vaccine-related menstrual cycle changes could be related to the timing of vaccination, with increased length observed among those who received vaccination during the first half of the menstrual cycle [34]. Brain fog, a symptom of cognitive decline, was consistently reported as a post-vaccination side effect in 4-6% of participants across vaccine doses in this study. A recent study showed that the odds of brain fog as a PCS symptom decreased with increasing vaccination rates [35]. While several mechanisms behind COVID-19-related brain fog have been proposed [36], further longitudinal and mechanistic investigation is required to understand vaccine-related brain fog.

Limitations

Our study has several limitations that should be acknowledged. First, participants were recruited through social media and recontacted from a previous study cohort, introducing potential selection bias. Individuals with more persistent or severe chemosensory symptoms, or those more motivated to report outcomes, may be overrepresented compared to the general population of COVID-19 survivors. Second, all data were self-reported, which introduces the potential for recall bias and misclassification. While self-report methods have been successfully used to capture chemosensory function in more recent studies[15–17], they do not offer the precision of standardized psychophysical testing[24]. Third, the natural history of COVID-19-associated chemosensory dysfunction involves gradual recovery in many individuals, making it difficult to disentangle vaccine-related changes from spontaneous improvement. Although our

analysis did not identify a relationship between time since vaccination and reported changes in smell or taste, the absence of longitudinal tracking and baseline objective measures limits our ability to isolate vaccine effects from ongoing recovery. Fourth, the survey period spanned multiple waves of infection and variant predominance, each of which may have had differing effects on chemosensory outcomes. Fifth, the possibility of self-selection bias remains, whereby individuals who noticed changes in their senses may have been more inclined to respond than those who experienced no change. Finally, differences in healthcare access, vaccine brand availability, and cultural factors across countries may have influenced both exposure and reporting patterns. These limitations constrain causal inference, and our findings should be interpreted as exploratory. Future longitudinal studies with objective assessments and time-matched controls are needed to validate these results.

Clinical Significance

Our study investigated a unique need for tailored vaccination strategies that consider individual health profiles and regional differences in vaccine response. While the pathophysiological mechanisms underlying the effect of vaccines on chemosensory perception remain unclear [37], the variability in side effects and chemosensory outcomes based on vaccine type underscores the importance of personalized approaches to vaccination, allowing healthcare providers to better manage patient expectations and improve compliance. The observation that mRNA vaccines maintain a consistent side effect profile while adenovirus vector vaccines show higher initial side effects that taper off suggests specific considerations for vaccine selection, particularly for patients with concerns about adverse reactions. Additionally, the potential therapeutic benefits of vaccination in improving certain chemosensory dysfunctions, such as parosmia, phantosmia, and taste distortions, offer new avenues for managing these conditions in patients affected by COVID-19. These insights are crucial for informing public health strategies, addressing vaccine hesitancy, and optimizing vaccination campaigns to ensure broader and more effective protection against COVID-19.

CONCLUSIONS

This global survey provides preliminary evidence that COVID-19 vaccination may be associated with changes in chemosensory dysfunction among individuals previously affected by COVID-19, particularly for qualitative symptoms such as parosmia and

phantosmia. Reported outcomes varied by vaccine type and brand, suggesting potential differences in immunological or sensory effects. These findings may inform patient counseling and guide future investigations into chemosensory recovery in the context of post-acute COVID-19 syndrome. However, results should be interpreted with caution given the limitations of self-reported data, non-random sampling, and the difficulty in disentangling vaccine-related effects from the natural course of recovery. Further longitudinal and controlled studies using objective assessments are needed to establish causal relationships and support the development of targeted interventions.

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AUTHORSHIP CONTRIBUTION

SK1, CMC, SK2, EC, MDG, JC, VP, VVV and LDH conceived the study. SK1, CMC, SK2, EC, MDG, JC, VP, KO, VVV and LDH designed the original survey. SK1, CMC, SK2, EC, SP, MDG, VH, SC, VP, JC, GC, KO, VVV and LDH translated and implemented the survey. SK1 and LDH set up the online survey. SK1, CMC, MAK, TKL, SK2, IGK, JY, MDG, VVV and LDH analyzed data. SK1, CMC, MAK, TKL, SK2, IGK, JY, MDG, VP, VVV and LDH interpreted data. SK1, CMC, SK2, EC, MDG, VP, JC, VVV and LDH administrated project. SK1, CMC, MAK, TKL, SK2, IGK, EC, MDG, VVV and LDH wrote the original manuscript. All authors reviewed and approved the final version of the manuscript. SK1, Sachiko Koyama; SK2, Svetlana Kopishinskaia.

CONFLICT OF INTEREST

KO works at dsm-firmenich. The company had no influence on the study design or interpretation of results. All other authors had no conflict of interest.

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FIGURES

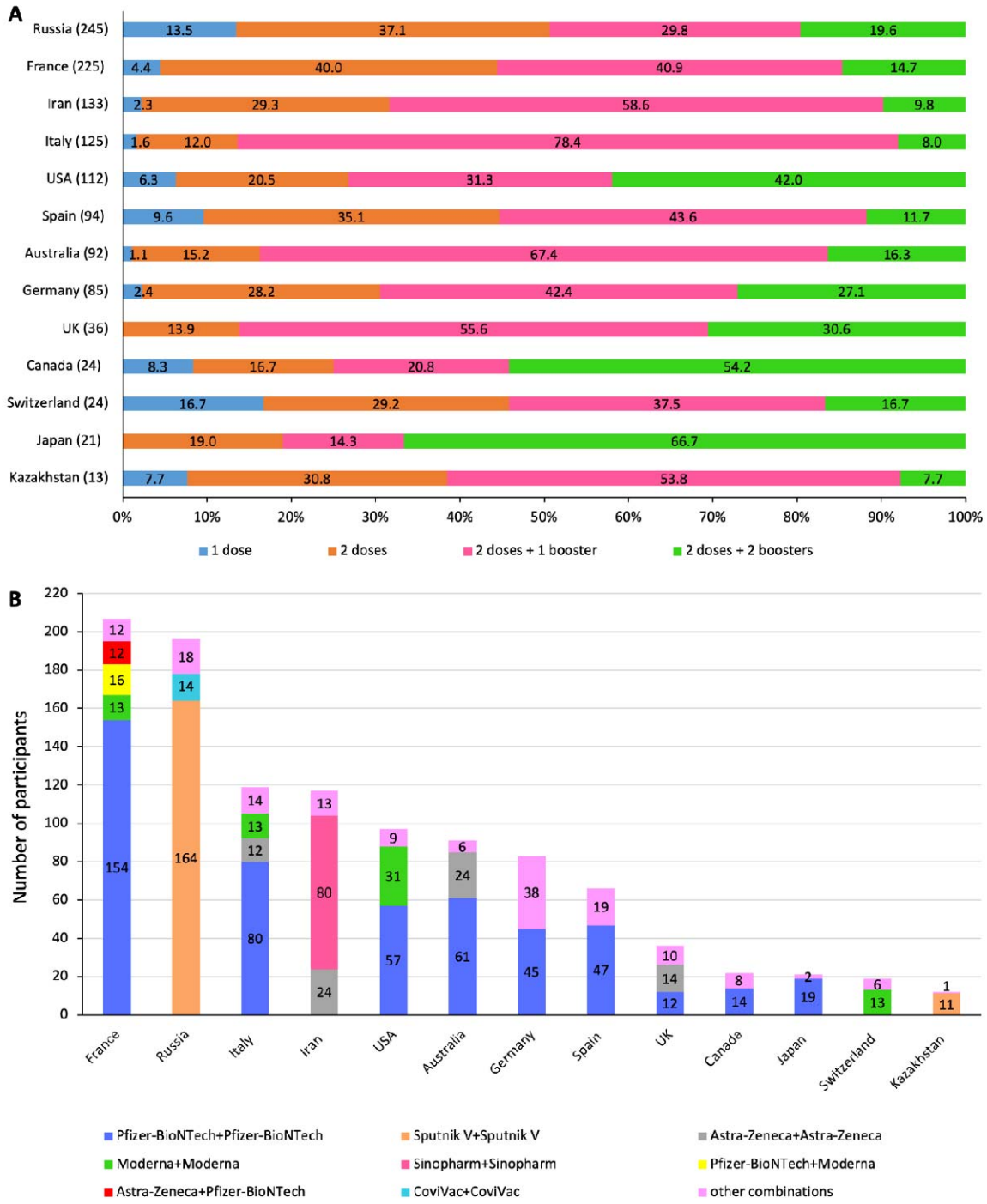

Figure 1. Distribution of vaccination status of participants (A) and combinations of the

first two doses received (B) in different countries. Only countries with ≥10 respondents were included. The number in brackets represents the total number of vaccinated participants per country.

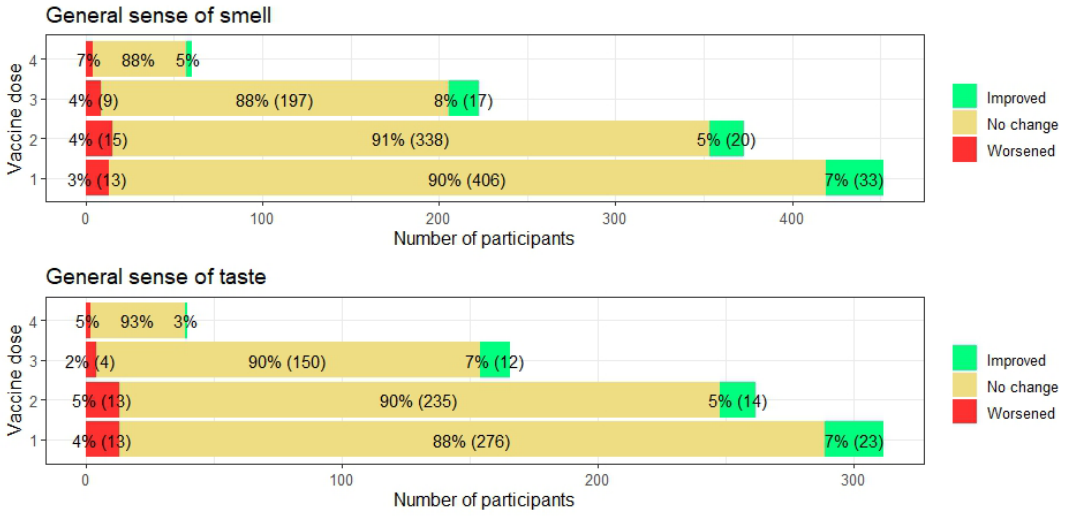

Figure 2. Changes in the senses of smell and taste after each dose of vaccine in participants with pre-existing chemosensory impairment due to COVID-19. The number of participants per condition for the first three doses is shown in parentheses.

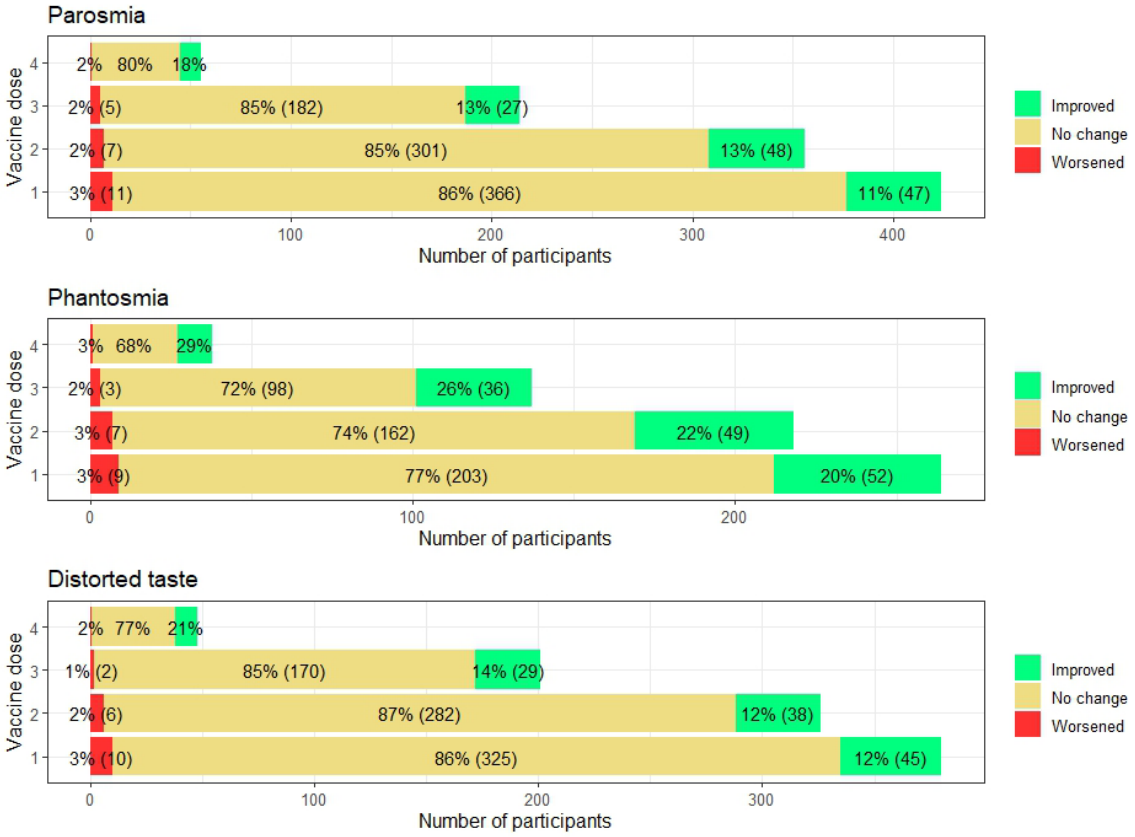

Figure 3. Changes in parosmia/phantosmia/distorted taste after each dose of vaccine in participants with pre-existing sensory impairment due to COVID-19. The number of participants per condition for the first three doses is shown in parentheses.

TABLES

Table 1. Changes in smell after the first dose and the second dose of the five most common vaccine brands.

After the first dose of vaccine						
Brands	**Vaccinated participants**	**Improved smell**		**Worsened smell**		**Improved vs worsened[f]**
	N	**N**	**Proportion**	**N**	**Proportion**	**P**
Pfizer-BioNTech[a]	598	18	3.0%	8	1.3%	0.08
Sputnik V[b]	246	2	0.8%	11	4.5%	0.02
Astra-Zeneca[b]	159	7	4.4%	7	4.4%	1
Moderna[a]	125	12	9.6%	4	3.2%	0.08
Sinopharm[c]	108	2	1.9%	2	1.9%	1
Total	1236	41	3.3%	32	2.6%	0.35
Fisher's Exact test of homogeneity, p-value[d]		$p < 0.001$		$p = 0.03$		
Significant post hoc test results, p-value unadjusted[d]		Pfizer-BioNTech vs Moderna, $p = 0.002$; Sputnik V vs Astra-Zeneca, $p = 0.03$; Sputnik V vs Moderna, $p < 0.001$; Moderna vs Sinopharm, $p = 0.01$		Pfizer-BioNTech vs Sputnik V, $p = 0.009$; Pfizer-BioNTech vs Astra-Zeneca, $p = 0.02$		
Significant post hoc test results, p-value adjusted[e]		Pfizer-BioNTech vs Moderna, $p = 0.02$; Sputnik V vs Moderna, $p < 0.001$		NS		
After the second dose of vaccine						
Pfizer-BioNTech[a] × 2	529	14	2.6%	4	0.8%	0.03
Sputnik V[b] × 2	194	3	1.5%	9	4.6%	0.15
Astra-Zeneca[b] × 2	108	3	2.8%	3	2.8%	1
Sinopharm[c] × 2	102	1	1.0%	2	2.0%	1
Moderna[a] × 2	99	7	7.1%	5	5.1%	0.77
Total	1032	28	2.7%	23	2.2%	0.58
Fisher's Exact test of homogeneity, p-value[d]		$p = 0.09$		$p = 0.002$		
Significant post hoc test results, p-value unadjusted[e]		Pfizer-BioNTech vs Moderna, $p = 0.03$; Sputnik V vs Moderna, $p = 0.03$; Sinopharm vs Moderna, $p = 0.03$		Pfizer-BioNTech vs Sputnik V, $p = 0.002$; Pfizer-BioNTech vs Moderna, $p = 0.007$		
Significant post hoc test results, p-value adjusted[e]		NS		Pfizer-BioNTech vs Sputnik V, $p = 0.02$		

Note: Brands with ≥95 respondents were included. All participants who received the first two doses of the same vaccine were included in the analysis of post-vaccination changes after the first dose of vaccine. [a]mRNA type vaccines; [b]adenovirus vector vaccines; [c]inactivated virus vaccines. [d]Fisher's test of homogeneity was used to compare the proportions of improvement or worsening between all groups. The following pairwise comparisons (post hoc) were also conducted with Fisher's test. [e]p-values are reported either unadjusted or adjusted for multiple comparisons using Holm method. [f]Binomial tests comparing the % improvement and % worsening with two-sided p-values reported. NS, no significant difference between all pairs.

Table 2. Post-vaccination changes in pre-existing parosmia by vaccine brands.

After the first dose of vaccine						
Brands	**Vaccinated participants**	**Improved parosmia**		**Worsened parosmia**		**Improved vs worsened[e]**
	N	**N**	**Proportion**	**N**	**Proportion**	**P**
Pfizer-BioNTech[a]	224	20	8.9%	4	1.8%	0.002
Moderna[a]	53	13	24.5%	0	0%	<0.001
Astra-Zeneca[b]	53	8	15.1%	4	7.5%	0.39
Sputnik V[b]	45	3	6.7%	1	2.2%	0.63
Total	375	44	11.7%	9	2.4%	<0.001
Fisher's Exact test of homogeneity, p-value[c]		p = 0.01		p = 0.08		
Significant post hoc test results, p-value unadjusted[d]		Pfizer-BioNTech vs Moderna, p = 0.004; Moderna vs Sputnik V, p = 0.03		Pfizer-BioNTech vs Astra-Zeneca, p = 0.046		
Significant post hoc test results, p-value adjusted[d]		Pfizer-BioNTech vs Moderna, p = 0.02		NS		
After the second dose of vaccine						
Pfizer-BioNTech[a] × 2	176	24	13.6%	1	0.6%	<0.001
Moderna[a] × 2	35	5	14.3%	0	0%	0.06
Sputnik V[b] × 2	38	6	15.8%	3	7.9%	0.51
Astra-Zeneca[b] × 2	25	1	4.0%	1	4.0%	1
Total	274	36	13.1%	5	1.8%	<0.001
Fisher's Exact test of homogeneity, p-value[c]		p = 0.54		p = 0.02		
Significant post hoc test results, p-value unadjusted[d]		NS		Pfizer-BioNTech vs Sputnik V, p = 0.02		
Significant post hoc test results, p-value adjusted[d]		NS		NS		

Note: The most common 4 brands were included. All participants who received the first two doses of the same vaccine were included in the analysis of post-vaccination changes after the first dose of vaccine. [a]mRNA type vaccines; [b]adenovirus vector vaccines. [c]Fisher's test of homogeneity was used to compare the proportions of improvement or worsening between all groups. The following pairwise comparisons (post hoc) were also conducted with Fisher's test. [d]p-values are reported either unadjusted or adjusted for multiple comparisons using Holm method. [e]Binomial tests comparing the % improvement and % worsening with two-sided p-values reported. NS, no significant difference between all pairs.

Table 3. Post-vaccination changes in pre-existing phantosmia by vaccine brands

Brands	Vaccinated participants	Improved phantosmia		Worsened phantosmia		Improved vs worsened[e]
	N	N	Proportion	N	Proportion	P
After the first dose of vaccine						
Pfizer-BioNTech[a]	152	26	17.1%	4	2.6%	<0.001
Moderna[a]	32	11	34.4%	3	9.4%	0.06
Astra-Zeneca [b]	30	6	20.0%	0	0%	0.03
Sputnik V[b]	23	6	26.1%	2	8.7%	0.29
Total	237	49	20.7%	9	3.8%	<0.001
Fisher's Exact test of homogeneity, p-value[c]		p = 0.15		p = 0.09		
Significant post hoc test results, p-value unadjusted[d]		Pfizer-BioNTech vs Moderna, p = 0.049		NS		
Significant post hoc test results, p-value adjusted[d]		NS		NS		
After the second dose of vaccine						
Pfizer-BioNTech[a] **× 2**	119	21	17.6%	6	5.0%	0.006
Moderna[a] **× 2**	22	7	31.8%	1	4.5%	0.07
Astra-Zeneca[b] **× 2**	18	1	5.6%	0	0%	1
Sputnik V[b] **× 2**	14	5	35.7%	0	0%	0.06
Total	173	34	19.7%	9	5.2%	<0.001
Fisher's exact test of homogeneity, p-value[c]		p = 0.07		p = 1		
Significant post hoc test results, p-value unadjusted[d]		NS		NS		
Significant post hoc test results, p-value adjusted[d]		NS		NS		

Note: The most common 4 brands were included. All participants who received the first two doses of the same vaccine were included in the analysis of post-vaccination changes after the first dose of vaccine. [a]mRNA type vaccines; [b]adenovirus vector vaccines. [c]Fisher's test of homogeneity was used to compare the proportions of improvement or worsening between all groups. The following pairwise comparisons (post hoc) were also conducted with Fisher's test. [d]p-values are reported either unadjusted or adjusted for multiple comparisons using Holm method. [e]Binomial tests comparing the % improvement and % worsening with two-sided p-values reported. NS, no significant difference between all pairs.