Long-Term Taste and Smell Outcomes After COVID-19
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Abstract

IMPORTANCE Self-report surveys suggest that long-lasting taste deficits may occur after SARS-CoV-2 infection, influencing nutrition, safety, and quality of life. However, self-reports of taste dysfunction are inaccurate, commonly reflecting deficits due to olfactory not taste system pathology; hence, quantitative testing is needed to verify the association of post–COVID-19 condition with taste function.

OBJECTIVE To use well-validated self-administered psychophysical tests to investigate the association of COVID-19 with long-term outcomes in taste and smell function.

DESIGN, SETTING, AND PARTICIPANTS This nationwide cross-sectional study included individuals with and without a prior history of COVID-19 recruited from February 2020 to August 2023 from a social media website (Reddit) and bulletin board advertisements. In the COVID-19 cohort, there was a mean of 395 days (95% CI, 363-425 days) between diagnosis and testing.

EXPOSURE History of COVID-19.

MAIN OUTCOMES AND MEASURES The 53-item Waterless Empirical Taste Test (WETT) and 40-item University of Pennsylvania Smell Identification Test (UPSIT) were used to assess taste and smell function. Total WETT and UPSIT scores and WETT subtest scores of sucrose, citric acid, sodium chloride, caffeine, and monosodium glutamate were assessed for groups with and without a COVID-19 history. The association of COVID-19 with taste and smell outcomes was assessed using analysis of covariance, χ², and Fisher exact probability tests.

RESULTS Tests were completed by 340 individuals with prior COVID-19 (128 males [37.6%] and 212 females [62.4%]; mean [SD] age, 39.04 [14.35] years) and 434 individuals with no such history (154 males [35.5%] and 280 females [64.5%]; mean [SD] age, 39.99 [15.61] years). Taste scores did not differ between individuals with and without previous COVID-19 (total WETT age- and sex-adjusted mean score, 33.41 [95% CI, 32.37-34.45] vs 33.46 [95% CI, 32.54-34.38]; P = .94). In contrast, UPSIT scores were lower in the group with previous COVID-19 than the group without previous COVID-19 (mean score, 34.39 [95% CI, 33.86-34.92] vs 35.86 [95% CI, 35.39-36.33]; P < .001). 103 individuals with prior COVID-19 (30.3%) and 91 individuals without prior COVID-19 (21.0%) had some degree of dysfunction (odds ratio, 1.64 [95% CI, 1.18-2.27]). The SARS-CoV-2 variant present at the time of infection was associated with smell outcomes; individuals with original untyped and Alpha variant infections exhibited more loss than those with other variant infections; for example, total to severe loss occurred in 10 of 42 individuals with Alpha variant infections (23.8%) and 7 of 52 individuals with original variant infections (13.5%) compared with 12 of 434 individuals with no COVID-19 history (2.8%) (P < .001 for all).

CONCLUSIONS AND RELEVANCE In this study, taste dysfunction as measured objectively was absent 1 year after exposure to COVID-19 while some smell loss remained in nearly one-third of (continued)
individuals with this exposure, likely explaining taste complaints of many individuals with post-
COVID-19 condition. Infection with earlier untyped and Alpha variants was associated with the
greatest degree of smell loss.

Introduction

Post–COVID-19 condition (PCC) is a significant national public health concern, occurring among 10
million to 35 million working-age adults in the US alone.1,2 Although PCC encompasses a diverse array
of new, recurring, or persistent health problems, effective health policy requires a precise
understanding of the prevalence of individual symptoms and their impact on daily life and work. Such
understanding is a prerequisite for providing survivors of COVID-19 with the types of support they
may need.

Reduced chemosensory function is one of the most frequently reported symptoms during the
acute phase of SARS-CoV-2 infection,3 with significant safety, nutrition, and quality of life outcomes.
However, very few studies have assessed taste and smell function in patients with COVID-19 over
intervals of 1 year or more after SARS-CoV-2 infection.4 Self-reports are inaccurate given that many
persons are unaware of a chemosensory disorder before being objectively tested5-11 and olfaction-
related loss of flavor is commonly misidentified as taste loss.12 While a 2023 meta-analysis13 of 235
studies concluded that taste loss was a distinct symptom of COVID-19, with a pooled prevalence rate
of 36.62, only 3.4% of the studies used empirical taste tests. Moreover, among these and other
studies using empirical tests, variable findings have been reported. For example, some studies
reported no meaningful association with mean taste test scores,14-16 whereas others denoted
prevalence rates ranging from 12% to 100%.17-23

This study had 6 main goals: (1) to examine a nationwide sample and evaluate long-term
outcomes associated with SARS-CoV-2 using a state-of-the-art, validated 53-item taste test; (2) to
compare taste findings with those from a widely used and reliable 40-item olfactory test; (3) to
investigate the proportion of individuals who continued to have differing degrees of taste or smell
dysfunction a mean of 1 year after their initial infection; (4) to investigate whether COVID-19 was
associated with different outcomes in the perception of sweet, sour, bitter, salty, and umami taste
qualities in such individuals; (5) to investigate whether age and sex were associated with test
findings; and (6) to investigate whether the viral variant prevalent at the time of initial diagnosis was
associated with test scores. To achieve these goals and minimize COVID-19–related selection bias,
participants were from a study in which COVID-19 was not an element of the recruitment process.

Methods

This study followed the Strengthening the Reporting of Observational Studies in Epidemiology
(STROBE) reporting guideline for cross-sectional studies, including recommended descriptions of
study design, participant selection, data sources, results, and discussion. All participants provided
signed written informed consent, and the study was reviewed and approved by the WIRB-
Copernicus Group Independent Review Board. Each participant was compensated $30 for
participating. This research complies with the Declaration of Helsinki for medical research involving
human participants.

Participants

Taste and smell tests described in the next section were completed by 774 participants. Recruitment
was made from advertisements placed on a social media website (Reddit) or local bulletin boards
and occurred from February 2020 to August 2023. The mean time between testing and COVID-19 diagnosis was 395 days (95% CI, 363-425 days). Participants came from 48 US states (there were no participants from Idaho or Hawaii). As shown in the Figure, the geographical frequency distribution of participants mirrored the relative populations of these states, underscored by a Spearman $r$ of 0.90 between the 2 sets of frequencies ($P < .001$). To minimize recruitment biases and oversampling of persons with COVID-19–related smell loss, COVID-19 was not mentioned in advertisements. Advertisements sought healthy persons who could “help in creating normative data for smell and taste tests, which will be used to track quality control and assess test-retest reliability.” Inclusion criteria included being healthy and not having a disorder aside from COVID-19 known to alter smell or taste function (eg, head trauma or neurodegenerative disease). Participant medical information, including history of COVID-19, dates of COVID-19 diagnosis, and method of diagnosis (polymerase chain reaction [PCR], antibody tests, and rapid tests), was collected. Data from individuals with more than 1 SARS-CoV-2 infection were excluded from analysis. If the participant did not follow instructions for self-administered tests (eg, not scratching or overscratching the odorant label or not completing response sheets), their data were excluded from the study. Race and ethnicity categories

Figure. Geographic Distribution of Study Participants and Corresponding State Population Percentages

A, This choropleth map depicts the geographic distribution of study participants across the US. The color intensity represents the number of participants in each state, with burgundy shades indicating higher participant counts. B, This map provides the percentage population of each state, offering a context for the distribution of participants.
are on the back of the University of Pennsylvania Smell Identification Test and were obtained by self-report; these categories were prevalent at the time of the development of the test. Available categories were African American, Asian, Hispanic, White, and other. These categories were used to better define the sampled population.

**Test Administration Procedures**

Tests described subsequently were provided to each participant, along with detailed instructions for self-administration. In most cases, tests were sent to participants through the mail. Participants were encouraged to contact the first author (R.S.) if questions arose. Completed tests were returned to R.S. for scoring.

Taste function was assessed using the well-validated 53-item self-administered Waterless Empirical Taste Test (WETT), a nonliquid test that requires no rinsing between trials. Test items consist of 53 1 × 6-cm plastic taste strips. Positioned on 1 side of each strip is a 1 × 2.5-cm monomer cellulose pad that contains a concentration of dried sucrose (0.20, 0.10, 0.05, or 0.025 g/ml), citric acid (0.025, 0.05, 0.10, or 0.20 g/ml), sodium chloride (NaCl; 0.0313, 0.0625, 0.125, or 0.25 g/ml), caffeine (0.011, 0.022, 0.044, or 0.088 g/ml), monosodium glutamate (MSG; 0.017, 0.034, 0.068, or 0.135 g/ml), or no stimulus. Strips are provided in convenient packs from which the participant removes each 1 in a numbered sequence for self-administration.

In a trial, the participant was instructed to move the cellulose pad of the strip around the mouth, particularly along the tip and edges of the tongue, for 5 to 10 seconds and to identify the taste quality from 5 categories listed on the response form (sweet, sour, salty, bitter, and brothy) or to indicate that no taste could be perceived. The WETT sequence involves presenting 4 concentrations of each stimulus twice. In the first half of the test, stimulus concentrations proceed from weak to strong in an ascending sequence, with different tastants presented in a random order except that no tastant immediately follows itself. Blanks, which help remove the residual of the prior stimulus, are interspersed after the higher concentrations of caffeine, NaCl, and citric acid. In the second half of the test, the reverse presentation order is made, going from strong to weak concentrations. The WETT is highly reliable, with test-retest and split-half reliability coefficients of 0.92 and 0.88, respectively.

Smell function was tested using the University of Pennsylvania Smell Identification Test (UPSIT), which has been administered to more than 1 million persons worldwide and is available in more than 50 languages. This 40-item forced-choice test focuses on the comparative ability of participants to identify odors at the suprathreshold level. It consists of 4 envelope-size booklets, each containing 10 scratch and sniff odorants embedded in 10- to 50-μm microcapsules positioned on brown strips at the bottom of each page. Above each odorant strip is a multiple choice question with 4 alternatives. The test score is the number of correct responses for 40 odorants. Internal consistency and test-retest reliability coefficients of this instrument are greater than 0.90, and its scores correlate strongly with other types of olfactory tests (eg, thresholds).

**Statistical Analysis**

Analysis of covariance was used to compare mean test scores between participants with a history of COVID and those with no such history. For taste, the dependent measure was the number of correct responses given to all 53 WETT stimulus presentations (total test score) and to the 8 trials of each of 5 subtests (sucrose, citric acid, NaCl, caffeine, and MSG). Within a subtest, the 4 concentrations were included as a repeated measures variable in models. For olfaction, the UPSIT score was the dependent measure. In most analyses, between-participant factors were COVID-19 history group and sex and the covariate was age. In some analyses, the virus variant prevalent at the time of testing also served as a factor and the time between initial infection and chemosensory testing served along with age as a covariate. The virus variant most common at the time of the initial infection was determined from Reiter et al. Smoking behavior was initially evaluated but excluded from subsequent analyses given that it was not significant and did not interact with any other variable. Post hoc comparisons were performed using the Tukey honestly significant difference test. Frequencies were evaluated...
using χ² or Fisher exact probability tests. Correlations were determined by the Pearson product moment correlation. All analyses were performed using Systat statistical software version 13.0 (Grafiti LLC). P values were 2-sided, and statistical significance was set at .05.

Results

Initially, 1074 individuals who met inclusion criteria were contacted and received test kits. Despite repeated follow-ups by the research coordinator (R.S.), 262 individuals did not return tests. Data from 5 individuals who failed to follow instructions were excluded from analysis. The final participant population consisted of 340 persons with a previous history of COVID-19 (128 males [37.6%] and 212 females [62.4%]; mean (SD) age, 39.04 (14.35) years; 18 African American [5.3%], 36 Asian [10.6%], 18 Hispanic [5.3%], and 198 White [58.2%]) and 434 persons with no such history (154 males [35.5%] and 280 females [64.5%]; mean (SD) age, 39.99 (15.61) years; 53 African American [12.9%], 47 Asian [10.8%], 30 Hispanic [6.9%], and 274 White [63.1%]). Demographic information, including age and sex, is presented in Table 1.

Taste

Total WETT scores did not differ significantly between participants with and without a COVID-19 history and fell within the normal normative range24 (age and sex-adjusted mean, 33.41 [95% CI, 32.37-34.45] vs 33.46 [95% CI, 32.54-34.38]; F[1,769] = 0.005; P = .94; η² < 0.000006). This was also true of subtest scores. Performance decreased as age increased (β per 1-year increase in age = −0.14; covariate F[1,769] = 37.98; P < .001; η² = 0.046).

Independent of COVID-19 history, females outperformed males on the total WETT score (mean, 35.08 [95% CI, 34.24-35.92] vs 31.78 [95% CI, 30.68-32.88]; F[1,769] = 21.95; P < .001; η² = 0.026). WETT subtest analyses also found better female than male performance for sucrose (mean, 4.94 [95% CI, 4.71-5.17] vs 3.92 [95% CI, 3.70-4.14]; F[1,769] = 20.66; P < .001; η² = .025), citric acid (mean, 5.58 [95% CI, 5.39-5.77] vs 5.24 [95% CI, 5.00-5.48]; F[1,769] = 4.88; P = .028; η² = .006), caffeine (mean, 4.98 [95% CI, 4.75-5.21] vs 3.92 [95% CI, 3.70-4.15]; F[1,769] = 27.49; P < .001; η² = 0.066).

Table 1. Demographic Characteristics of Study Participants

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Participants, No. (%) (N = 774)</th>
<th>Negative COVID-19 history (n = 434)</th>
<th>Positive COVID-19 history (n = 340)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>154 (35.48)</td>
<td>128 (37.65)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>280 (64.52)</td>
<td>212 (62.35)</td>
<td></td>
</tr>
<tr>
<td>Age, mean (95% CI), y</td>
<td>39.99 (38.52-41.47)</td>
<td>39.04 (37.51-40.57)</td>
<td></td>
</tr>
<tr>
<td>Race and ethnicity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>African American</td>
<td>56 (12.91)</td>
<td>18 (5.29)</td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>47 (10.83)</td>
<td>36 (10.59)</td>
<td></td>
</tr>
<tr>
<td>Hispanic</td>
<td>30 (6.91)</td>
<td>18 (5.29)</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>274 (63.13)</td>
<td>198 (58.24)</td>
<td></td>
</tr>
<tr>
<td>Other or not available</td>
<td>4 (6.22)</td>
<td>4 (20.59)</td>
<td></td>
</tr>
<tr>
<td>Smoking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>297 (68.43)</td>
<td>235 (69.12)</td>
<td></td>
</tr>
<tr>
<td>Past</td>
<td>81 (18.67)</td>
<td>76 (22.35)</td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>50 (11.52)</td>
<td>19 (5.59)</td>
<td></td>
</tr>
<tr>
<td>Not available</td>
<td>6 (1.38)</td>
<td>2 (2.94)</td>
<td></td>
</tr>
<tr>
<td>COVID-19 diagnosis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCR</td>
<td>NA</td>
<td>108 (31.76)</td>
<td></td>
</tr>
<tr>
<td>Rapid test</td>
<td>NA</td>
<td>100 (29.41)</td>
<td></td>
</tr>
<tr>
<td>Antibody</td>
<td>NA</td>
<td>11 (3.24)</td>
<td></td>
</tr>
<tr>
<td>Not available</td>
<td>NA</td>
<td>121 (35.59)</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: PCR, polymerase chain reaction; NA, not applicable.
η² = .033), and NaCl (mean, 5.61 [95% CI, 5.42-5.80] vs 5.17 [95% CI, 4.92-5.42]; F [1,769] = 7.39; P = .007; η² = 0.010)). No significant sex difference was found for MSG.

There were no significant differences among test scores of patients with different methods of diagnosis. No significant differences were evident in test scores among major SARS-CoV-2 variants extant at the time of disease onset (original untyped, Alpha, Delta, and Omicron) (Table 2).

### Smell

Unlike outcomes for taste, mean UPSIT scores were significantly lower in the group with PCC history than the group without PCC history (age and sex-adjusted mean, 34.39 [95% CI, 33.86-34.92] vs 35.86 [95% CI, 35.39-36.33]; 4.2% reduction; F [1,769] = 1716; P < .001; η² = 0.021). Although females had higher scores than males, this difference was not statistically significant (mean, 35.37 [95% CI, 34.94-35.80] vs 34.88 [95% CI, 34.33-35.43]; F [1,769] = 1.89; P = .17; η² = 0.002).

Performance decreased as age increased (β per 1-year increase in age = −0.06; F [1,769] = 31.71; P < .001; η² = 0.039).

Individuals with a history of COVID-19 were more likely to experience some degree of smell loss compared with those without such a history (103 individuals [30.3%] vs 91 individuals [21.0%]; odds ratio, 1.64 [95% CI, 1.18-2.27]; P < .001). The incidence of anosmia or severe microsmia was higher in the group with a history of COVID-19 compared with the group without such a history (29 individuals [8.5%] vs 12 individuals [2.8%]; OR, 3.28 [95% CI, 1.65-6.53]; P < .001).

In assessment of differences in UPSIT scores by SARS-CoV-2 variant extant at the time of SARS-CoV-2 infection, there was a significant difference by variant (F [3,330] = 6.58; P < .001; η² = 0.052).

In post hoc analyses, the mean UPSIT score among individuals with Omicron variant infection (35.19 [95% CI, 34.54-35.84]) was significantly higher than those of individuals with the original (33.11 [95% CI, 31.81-34.41]) and Alpha (32.30 [95% CI, 30.83-33.77]) variant infections (P values = .001). Test scores of participants with the original and Alpha variant infections were the only ones to differ

### Table 2. WETT Scores by Major Extant Virus Variant at Testing

<table>
<thead>
<tr>
<th>WETT component</th>
<th>No COVID-19 history (n = 434)</th>
<th>SARS-CoV-2 variant</th>
<th></th>
<th></th>
<th>P valuea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweet (sucrose)</td>
<td>4.77 (4.55-4.99)</td>
<td>4.56 (4.90-5.22)</td>
<td>4.69 (4.34-5.44)</td>
<td>4.41 (3.55-5.27)</td>
<td>4.71 (4.38-5.04)</td>
</tr>
<tr>
<td>Sour (citric acid)</td>
<td>5.30 (5.10-5.50)</td>
<td>5.09 (4.52-5.66)</td>
<td>5.86 (5.22-6.50)</td>
<td>5.56 (4.82-6.30)</td>
<td>5.55 (5.27-5.83)</td>
</tr>
<tr>
<td>Salty (NaCl)</td>
<td>5.36 (5.15-5.57)</td>
<td>4.83 (4.23-5.43)</td>
<td>5.63 (4.96-6.30)</td>
<td>5.40 (4.62-6.18)</td>
<td>5.52 (5.22-5.82)</td>
</tr>
<tr>
<td>Bitter (caffeine)</td>
<td>4.50 (4.25-4.75)</td>
<td>4.52 (3.80-5.24)</td>
<td>3.99 (3.18-4.80)</td>
<td>3.63 (2.70-4.56)</td>
<td>4.53 (4.18-4.88)</td>
</tr>
<tr>
<td>Brothy (MSG)</td>
<td>3.09 (2.68-3.50)</td>
<td>2.77 (2.09-3.45)</td>
<td>2.99 (2.23-3.75)</td>
<td>2.20 (1.32-3.08)</td>
<td>2.80 (2.46-3.14)</td>
</tr>
<tr>
<td>Total</td>
<td>33.39 (32.48-34.30)</td>
<td>32.97 (30.35-35.59)</td>
<td>33.43 (30.48-36.38)</td>
<td>32.22 (28.83-35.61)</td>
<td>33.82 (32.53-35.11)</td>
</tr>
</tbody>
</table>

Abbreviations: NaCl, sodium chloride; MSG, monosodium glutamate; WETT, Waterless Empirical Taste Test.

a P values are based on analyses of covariance with age as the covariate and sex and SARS-CoV-2 variant common at the time of initial infection as between-participant factors.

### Table 3. Relative Frequencies of Olfactory Dysfunction

<table>
<thead>
<tr>
<th>Dysfunctiona</th>
<th>Participants, No. (%) (N = 774)b</th>
<th>No COVID-19 history (n = 434)</th>
<th>Omicron variant (n = 214)</th>
<th>Delta variant (n = 32)</th>
<th>Alpha variant (n = 42)</th>
<th>Original variant (n = 52)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normosmia</td>
<td>343 (79.0)</td>
<td>161 (75.2)</td>
<td>23 (71.9)</td>
<td>22 (52.4)</td>
<td>31 (59.6)</td>
<td></td>
</tr>
<tr>
<td>Mild to moderate loss</td>
<td>79 (18.2)</td>
<td>43 (20.1)</td>
<td>7 (21.9)</td>
<td>10 (23.8)</td>
<td>14 (26.9)</td>
<td></td>
</tr>
<tr>
<td>Severe to total loss</td>
<td>12 (2.8)</td>
<td>10 (4.7)</td>
<td>2 (6.2)</td>
<td>10 (23.8)</td>
<td>7 (13.5)</td>
<td></td>
</tr>
</tbody>
</table>

a Severe to total smell loss indicates University of Pennsylvania Smell Identification Test (UPSIT) scores between 6 and 25; mild to moderate loss indicates UPSIT scores of 26 to 33 for males and 26 to 34 for females; normosmia indicates UPSIT scores greater than 33 for males and greater than 34 for females. Note the greater dysfunction among individuals with Alpha and Original variant SARS-CoV-2 infections.

b Individuals with past infections are categorized into variant-specific subgroups listed from most recent to oldest extant variety.
significantly from test scores of participants with no history of COVID-19. For example, total to severe loss occurred in 10 of 42 individuals with the Alpha variant infection (23.8%) and 7 of 52 individuals with the original variant infection (13.5%) compared with 12 of 434 individuals with no COVID-19 history (2.8%) (P values < .001) (Table 3).28

Relative frequencies of UPSIT dysfunction categories are presented in Table 3 for individuals with infection by each of 4 SARS-CoV-2 variants prevalent at the time of infection and for individuals with no history of COVID-19. Frequencies correlate with the severity of smell loss scores given previously.

Correlation Between Taste and Smell Tests
Within groups with (Pearson r = 0.18; P < .001) and without (Pearson r = 0.27; P < .001) COVID-19 history, UPSIT and total WETT scores were correlated. This suggests some degree of common sensitivity of participants between these 2 sensory systems.

Discussion
The major finding of this cross-sectional study was that taste function was not meaningfully altered 1 year after having COVID-19 as determined by a well-validated 53-item taste test. In contrast, some degree of olfactory dysfunction remained in nearly one-third of individuals with PCC as measured by the 40-item UPSIT. However, unlike acute cases,5 the effect size as measured by η² was not large, likely reflecting the marked improvement that occurred over time. Reports that taste loss continues long after the initial infection probably are due in large part to the confusion between taste- and olfaction-dependent food flavor. The latter is due to molecules reaching the olfactory receptors from the oral cavity via the nasopharynx.33 Taste buds mediate only sweet, sour, bitter, salty, and umami oral sensations.

This study’s findings suggest that the relative degree of smell loss associated with each SARS-CoV-2 variant remained consistent for at least 1 year after infection. Our finding that more recent SARS-CoV-2 variants, most notably Omicron, exhibited less frequent smell loss accords with findings from earlier studies.34-36 For example, Varia et al36 examined smell function within 10 days of symptom onset of patients whose COVID-19 was due to infection with the same SARS-CoV-2 variants we examined. The authors found that the prevalence of smell loss of persons with Omicron variant infections (36.3%) was significantly lower than that of persons with the original variant (80.6%), Alpha variant (83%), and Delta variant (65.6%). Graf et al35 also found olfactory dysfunction prevalence and severity to be lower for patients with Omicron variant (56%) than Delta variant (79%) infections.

In our study, age-associated declines were observed for all test measures, including WETT and its subscales and UPSIT. These findings are in accord with a large body of evidence suggesting that age may be the most important participant variable associated with taste and smell function.35,37 It is noteworthy that age did not interact with test scores among individuals with or without a history of COVID-19, suggesting its relative independence from sensory outcomes associated with SARS-CoV-2 infection.

In this study, taste test scores were significantly higher for females than males for the overall WETT and sucrose, citric acid, caffeine, and NaCl subtests. However, this was not the case for the MSG subtest or the UPSIT. The basis for the lack of a sex difference for these measures is not clear given that we had previously found that females significantly outperformed males on the UPSIT37 and all 5 WETT subtests.25,26,38 In the MSG subtest and UPSIT, however, scores were higher in females than males, although these differences were not significant.

Strengths and Limitations
Our study has several strengths and weaknesses. Among its strengths is the quantitative assessment of taste and smell function 1 year or more after the viral infection, providing a longer evaluation
period than is typical of most PCC studies. A second strength is our study’s use of well-validated self-administered taste and smell tests. Self-administration eliminates interactions between participants and test examiners during testing, precluding potential examiner influences on test results. Home testing has been shown to be equivalent to laboratory testing for the UPSIT\textsuperscript{39} and is likely the case for the WETT. In addition, study participants were not selected a priori for inclusion in COVID-19 and non–COVID-19 groups; combined with the self-administration procedure, this may be compared with a double-blind study in which participants are unaware of assignment to a study group and examiners are blind to participant performance and the assigned study group. Another strength of the study was its use of analysis of covariance in which age and time between testing and COVID-19 diagnosis were controlled for some analyses.

Limitations of the study include the lack of multiple test periods after the initial viral infection and the inference of the SARS-CoV-2 variant based on extant viruses present at the time of testing. Although the collection of several additional variables may have been useful in analyses, we found that neither age nor sex were specifically associated with COVID-19–related taste or smell scores. However, these measures were associated with test scores of both groups. This is in accord with a large meta-analysis of gustatory dysfunction in COVID-19 performed by Liu et al\textsuperscript{40} that found that neither of these 2 variables or a large number of other variables, including cigarette smoking, interacted with COVID-19’s association with taste function. While PCR testing is optimal for identifying exact variants, our study faced limitations in accessing PCR data, which precluded precise variant inference. As a result, the method of inferring variants based on infection timing was chosen as an alternative approach, which has been used by other investigators as well.\textsuperscript{31}

Conclusions

In this nationwide cross-sectional study of participants with and without a history of COVID-19, empirically measured taste function was normal 1 year after exposure to COVID-19. However, smell loss remained in nearly one-third of individuals with exposure, likely explaining taste complaints of many individuals with PCC. Earlier untyped and Alpha SARS-CoV-2 variants were associated with the greatest degree of smell loss.

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Concept and design: Sharett, Moein, Doty.

Acquisition, analysis, or interpretation of data: All authors.

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Administrative, technical, or material support: Sharett, Khan.

Supervision: Moein, Doty.
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REFERENCES


SUPPLEMENT.
Data Sharing Statement