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Article

Detection of Symptomatic and Asymptomatic SARS-CoV-2 by Naïve Dogs: Feasible in Controlled Tasks but Envisioned as Limited for Public Screening

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Abstract

Dogs can detect volatile organic compounds (VOCs) associated with infectious diseases, but their ability to distinguish between symptomatic and asymptomatic SARS-CoV-2 infections has not been fully established. In this study, eight naïve dogs began training with either symptomatic or asymptomatic Delta samples; seven reached the testing phase and were then evaluated on the alternate group to assess cross-generalization. Training initially used a yes/no protocol but was adapted to a line-up design after poor performance. When presented with novel Delta samples, dogs significantly discriminated them from controls, achieving a mean sensitivity of 71% and specificity of 51%, with no difference between training groups. In contrast, performance dropped when dogs were tested with asymptomatic Omicron samples from vaccinated individuals, with a mean sensitivity of 55%. These results show that dogs can generalize across symptomatic and asymptomatic COVID-19 cases for the Delta variant but fail to detect Omicron reliably, likely due to altered VOC profiles in vaccinated individuals. While proof-of-concept feasibility was demonstrated with a line up protocol for detecting asymptomatic scent, detection dogs should not currently be recommended for large-scale screening, but findings underscore the need for standardized protocols and variant-specific retraining.

Keywords: scent detection; dogs; covid; volatile organic compounds; asymptomatic; symptomatic; COVID-19

1. Introduction

Several diseases are known to produce specific scents in patients, which are excreted as volatile organic compounds (VOC) and can be detected within seconds by dogs. Medical detection dogs show great potential for use as alternative diagnostic tools not only for organic diseases (Reeve et al., 2021), for example, epileptic or diabetic crisis (Catala et al., 2019; Hardin et al., 2015), or cancer (Bauër et al., 2022), but also infectious diseases (Angle et al., 2015; Aksenov et al., 2014).

The detection of scents produced by infections involves distinct challenges compared to those associated with organic diseases. Variables include differences in viral load, the symptomatic state of

individuals (ranging from symptomatic to pre-symptomatic and asymptomatic), the context in which the dog is working, and the evolution of viral variants over time. Another underlying issue is whether the detectable scent originates from the virus's metabolism itself or from the abnormal functioning of affected organs (lungs, liver, sinuses, intestines, etc.); this issue is unclear at the moment remaining unresolved (Otto et al., 2021). Additionally, organs' state and medication use can vary widely between persons based on their metabolic conditions, further increasing the variability of scent profiles. This variability poses a significant challenge for dogs tasked with identifying virus-positive individuals. Achieving consistent performance under such variable conditions likely depends on dogs reaching a sufficient and standardized level of training (Gadbois & Reeve, 2014, 2016).

During the 2020-2023 SARS-CoV-2 pandemic, in particular due to pre- or asymptomatic transmission, disease control remained challenging (e.g. Halfon et al., 2021). For COVID-19 detection, dogs have been used to complement the RT-PCR (reverse transcription polymerase chain reaction) conventional detection method. In the systematic review by Meller et al. (2023), the use of dogs' olfaction as a reliable COVID-19-screening tool has been evaluated. Twenty-seven studies from thirteen countries were used as material for two independent procedures for study quality assessment. Potential confounding factors, such as study design, patient/sample selection, dog characteristics, training protocols, and sample types/treatment, were considered. Only four and six studies had low risk of bias and high quality, respectively. Further, these studies indicated that dogs distinguished between COVID-19 positive and negative persons: whereas the four QUADAS-2 non-biased studies revealed sensitivity and specificity ranging from 81–97% and 91–100%, the six high-quality studies, according to the general evaluation system, resulted in sensitivity and specificity ranging from 82–97% and 83–100%, respectively. The other studies presented methodological, quality, and bias concerns. Note that the variants or the presence of symptoms in COVID-19-positive persons were not specifically addressed as a factor in the study. Given the small number of papers that remained sufficiently reliable to be analyzable by Meller et al. (2023) concluded that, as for canine explosives detection, standardization and certification procedures should be established for medical scent detection dogs.

A major challenge for controlling the spread of a virus in the population is the detection of symptomatic (S) or asymptomatic (AS) patients against controls (C), or more importantly, through distinguishing all three statuses. To our knowledge, no study has specifically examined whether dogs can discriminate between symptomatic, asymptomatic, and control individuals in the case of COVID-19.

Research in related areas provides useful insights. Three studies have investigated scent detection by dogs and electronic noses (eNose) in other infectious diseases. Guest et al. (2019) showed that trained dogs identified asymptomatic malaria-infected individuals by their scent, suggesting a role for canine detection at borders or in malaria-elimination regions. In a later study, Guest et al. (2022) trained dogs to recognize the scent of asymptomatic SARS-CoV-2 cases (patients not requiring hospitalization, able to walk short distances, and stand for up to 15 minutes). Both dogs and Organic Semiconductor sensors (OSC) detected asymptomatic and mild cases with a high degree of accuracy under laboratory conditions. However, they did not compare asymptomatic with symptomatic patients directly, leaving unresolved whether dogs could generalize across these groups, the central aim of our study. Similarly, Grandjean et al. (2022) reported that dogs achieved a higher sensitivity than nasopharyngeal antigen testing, though with lower specificity. **While this highlights the diagnostic potential of canine scent detection, the study did not assess whether detection varied by symptom status, which we addressed explicitly in the present work.**

Together, these findings demonstrate that trained dogs can detect asymptomatic infection under controlled conditions. However, it remains unclear whether dogs can generalize between symptomatic and asymptomatic patients, a question that previous studies did not directly address and which forms the central focus of our investigation.

In another study, Bax et al. (2022) used an electronic nose (eNose) to analyze exhaled breath from 33 SARS-CoV-2-infected patients, 25 suffering from respiratory failure, and 8 asymptomatic, as well

as 22 control subjects. The features identified by the Boruta algorithm were significantly different in SARS-CoV-2 patients with respiratory failure compared to both controls and asymptomatic SARS-CoV-2 patients. This finding indicates that VOC signatures may vary depending on symptom severity and clinical status. It underscores the need to test whether detection dogs face similar challenges when distinguishing between symptomatic and asymptomatic cases, a key focus of our study.

Ungar et al. (2023) trained two dogs with heterogeneous samples, including Alpha from hospitalized patients and Alpha, Delta, and Omicron from known COVID-19–positive individuals. During testing, these dogs achieved high agreement rates (95–96% positive, 94–96% negative) and remained accurate even with Omicron subvariants, suggesting that VOC profiles may be stable across variants. Interestingly, the dogs also alerted to an asymptomatic relative who later tested PCR-positive, highlighting their potential to detect infection before clinical confirmation. In contrast, Ozgur et al. (2023) reported inconsistent VOC signatures across SARS-CoV-2 variants, indicating that olfactory detection may not always generalize across viral evolution.

There is increasing interest in utilizing trained dogs as alternative methods for screening asymptomatic individuals for infectious diseases (Grizzi et al., 2024). However, detection accuracy has been shown to vary depending on the virus and study design. This variability reinforces the importance of developing standardized protocols for canine detection. In our study, we address this issue directly by discussing the yes/no and line-up procedures under controlled conditions.

A final issue concerns the training protocols used for canine scent detection. Two main approaches exist: line-up protocols, which assess relative discrimination among multiple samples, and yes/no procedures, which test absolute recognition of an odor signature. Each has strengths and limitations; here, we evaluated both under controlled conditions (Gadbois & Reeve, 2014, 2016).

This study aimed to determine whether dogs trained on symptomatic COVID-19 patients could detect asymptomatic cases, and vice versa, and to test whether such generalization was preserved across viral variants (Delta vs. Omicron). To address this, we used two detection protocols (yes/no vs. line-up) under controlled, double-blind conditions. Because of infection control challenges in early 2021 (Ozgur et al., 2023), we initially adopted the yes/no procedure, which is considered a conservative method, before later transitioning to the line-up protocol. This design allowed us to assess the strengths and weaknesses of both approaches and to directly evaluate whether symptomatic and asymptomatic SARS-CoV-2 infections produce discriminable odor signatures, and whether detection performance was maintained across different variants.

.Given all confounding factors earlier mentioned, among them the distinguishability of asymptomatic vs. symptomatic COVID19 scent, we wondered whether there would exist distinguishable scent for symptomatic and asymptomatic persons. We thus designed a proof-of-concept study creating a protocol never designed earlier for scent detection dogs: it aimed at determining whether asymptomatic (AS) SARS-Cov-2 infected patients could be detected by detection dogs trained to recognize odor of symptomatic (S) SARS-Cov-2 infected patients, and conversely, what has never been studied earlier. Given the infection control challenges in January 2021 (Ozgur et al., 2023) and because line-up paradigm limits specificity and reliability computations, to use a conservative learning and test protocol, we choose the second one, Yes/No.

Given the lack of data indicating that human scent for viruses emanates from damaged human tissues or from virus activities themselves, as well as the metabolism variabilities between people, we granted this study as exploratory: no specific hypothesis is proposed. We finally hypothesized that dogs that performance might decline with newer viral variants such as Omicron

2. Materials and Methods

To address these aims, we conducted a randomized, double-blind, prospective study comparing the performance of naïve dogs trained to detect symptomatic versus asymptomatic COVID-19 cases, first using a yes/no protocol and later a line-up procedure. The study was approved by the French institutional review board for human studies (CPP SUD-EST I) and conducted in accordance with the

Declaration of Helsinki, Good Clinical Practices, and local ethical and legal requirements (trial registration: ClinicalTrials.gov NCT04970563). Informed consent was obtained from all patients prior to sample collection. The Animal Ethics Committee n° 71 of Marseille/France reviewed the project and confirmed that no authorization was required, as the protocol did not affect dog welfare.

2.1. Material

2.1.1. Human Participants' Scent Sampling

2.1.1.1. Subjects

A total of 160 human subjects (≥ 18 years old) were included in the study, by Hôpital Européen in Marseille. All participants were screened for COVID-19 using RT-qPCR with a nasopharyngeal swab (Delta) from June 2021 to January 2022. RT-qPCR testing was performed under routine conditions by using the UltraGene Combo2Screen SARS-CoV-2 Assay (ref 139b) (ABL SA Group, Luxembourg) and Chemagic™ viral DNA/RNA 300 kit H96 (ref. CMG-1033-S) on a Chemagic™ 360-D instrument (PerkinElmer, Inc., Austin, TX) according to the manufacturer's instructions [PerkinElmer. Instructions for the Perkin Elmer new coronavirus nucleic acid detection kit. V6.0. 2020].

AS patients (N=50) presented positive RT-PCR for SARS-COV-2 without any symptoms (fever, cough, anosmia, diarrhea). S patients (N=50) presented positive RT-PCR for SARS-COV-2 with at least one symptom (fever, cough, anosmia, diarrhea). Healthy persons/controls (N= 60) presented negative RT-PCR for SARS-COV-2 and no symptoms (fever, cough, anosmia, diarrhea) at Day 0 and Day 7.

All participants were recruited after the RT-PCR test results were sent from the European Hospital laboratory to the principal investigator (FR). To increase sample diversity, participants were included from different populations: inpatients, outpatients, at-home patients, physicians, nurses, and staff members from the hospital.

Demographic data (age, sex, body mass index), symptomatic status (for symptomatic patients: presence of fever, cough, anosmia, diarrhea), comorbidities and risk factors (tobacco use, diabetes, hypertension, dyslipidemia, cardiovascular disease, active cancer, severe renal failure), previous COVID-19 infection and vaccinal status (0 to 3 doses and type of vaccines when available) were recorded.

Inclusion criteria were:

- 18 years of age or older,
- free, informed, and express consent,
- affiliation with or coverage by a social security plan,
- patients infected with SARS-CoV-2 with positive RT-PCR on nasopharyngeal or salivary swabs and no symptoms (fever, cough, anosmia, fever) were included in the group of asymptomatic group. N = 50,
- patients infected with SARS-CoV-2 with positive RT-PCR on nasopharyngeal or salivary swabs and at least one symptom (fever, cough, anosmia, and/or diarrhea) were included in the symptomatic group. N= 50,
- participants not infected with SARS-CoV-2, with negative RT-PCR on nasopharyngeal or salivary swabs and no symptoms (fever, cough, anosmia, diarrhea) at Day 0 and Day D7 were included in the Healthy control group. N = 60.

Non-inclusion and exclusion criteria for creating scent samples:

- persons under legal protection measures or the safeguard of justice,
- life expectancy of less than 3 months.

Healthy controls with positive RT-PCR tests at Day 7 were excluded from the control. Then,

- if asymptomatic, samples (body sweat compresses and masks) were collected, and participants were integrated into the asymptomatic group.
- If symptomatic, they were excluded from the study, and their samples were destroyed.

2.1.1.2. Odor's Samples

Once participants were assigned to one of the three groups, samples were collected either at Hôpital European Marseille or at the participant's home. Sweat samples and breath odor were self-collected by patients under the supervision of the healthcare staff (physician) who instructed them on the procedure.

To avoid contamination, the physician wore two pairs of new gloves, FFP2 masks, and full COVID-19 safety protective equipment when collecting all samples (regardless of the COVID-19 status). A new set of protective equipment was used for each participant. For each participant, six consecutive identical samples were collected.

For the sample collection procedure, participants were asked to wear a surgical mask for one minute, and a 2x2-inch gauze swab was rubbed on the inguinal area and then kept in contact with the skin for one minute. Both mask and gauze swabs were inserted in a hermetic safety bag (95KpA) by the participants. The safety bag was placed in two additional insulating bags (triple packaging). The procedure was repeated six times for each participant, producing six series of samples per participant. We assumed equivalent volatile compound concentration across repeated samples.

2.1.1.3. Storage and Mailing Procedure

The samples were next stored for at least 14 days in a dedicated freezer (-20°C) at the European Hospital laboratory to limit bacterial growth and reduce viral viability on the masks and sweat samples. However, prior research has shown that SARS-CoV-2 can remain stable and potentially infectious at freezing temperatures (-20 °C) for extended periods (Van Doremalen et al., 2020). Therefore, subsequent storage at ultra-low temperatures (-80 °C) was used to maximize biosafety and sample integrity.

Samples collected were divided (see below), sent, and stored by the detection dog teams (ACADIA and ANIMALIN) in a dedicated refrigerator until use (i.e., within two weeks of receipt) in a secure room, first for the training phase, and later for the test phase only (ACADIA school only).

2.1.2. Dog Participants

Eight dogs were recruited for this study, aged between 1.5 and 9 (mean = 4.06, SD = 3.05), six males and two females.

Two dog training organizations each provided four of the dogs participating in the study: ACADIA, a not-for-profit organization dedicated to the training of service dogs as diabetes alert dogs, and Animalin, a pet dog training school utilizing scent training in sports and in behavior modification protocols. All the dogs lived with their respective owners and came to the training center 2 to 4 times per week over a four-month period of training and preparation. The dogs were of a variety of breeds and breed mixes and came from diverse backgrounds, most from shelters and rescues (see Table 1). They were selected for their high sociability, their ability to adapt to novel situations, and their good health. They had received prior basic obedience training but had no prior experience in scent detection. Dogs were not selected based on specific suitability for scent discrimination.

Table 1. Characteristics of dog participants.

Dog	Breed	Age in years	Sex
Blaike	Mix breed	7	Male
Ghost	Australian shepherd mix	2	Male
Lina	Mix breed	7	Female
Orco	Labrador	2	Male
Icare	Jack Russell Terrier	9	Male
Peps	Shepherd mix	2	Male
Perle	Labradoodle	2	Female
Ramses	Labrador	1.5	Male

2.2. Experimental Setup for the Testing Phase and Behavioral Analysis

The testing phase was conducted in a spacious room at the ACADIA headquarters (8m x 6m) (see Figure 1). Two cameras mounted on tripods were strategically positioned within the room to record the dogs' behavior (Cameras 1 & 2). A third camera (Camera 3), connected directly to a computer, allowed for real-time remote monitoring.

A remote treat dispenser (Pet Tutor) was placed inside the testing room to deliver rewards, which were triggered by an experimenter stationed in an adjacent control room. This setup ensured that reinforcement could be provided promptly while minimizing the experimenter's influence on the dog's behavior.

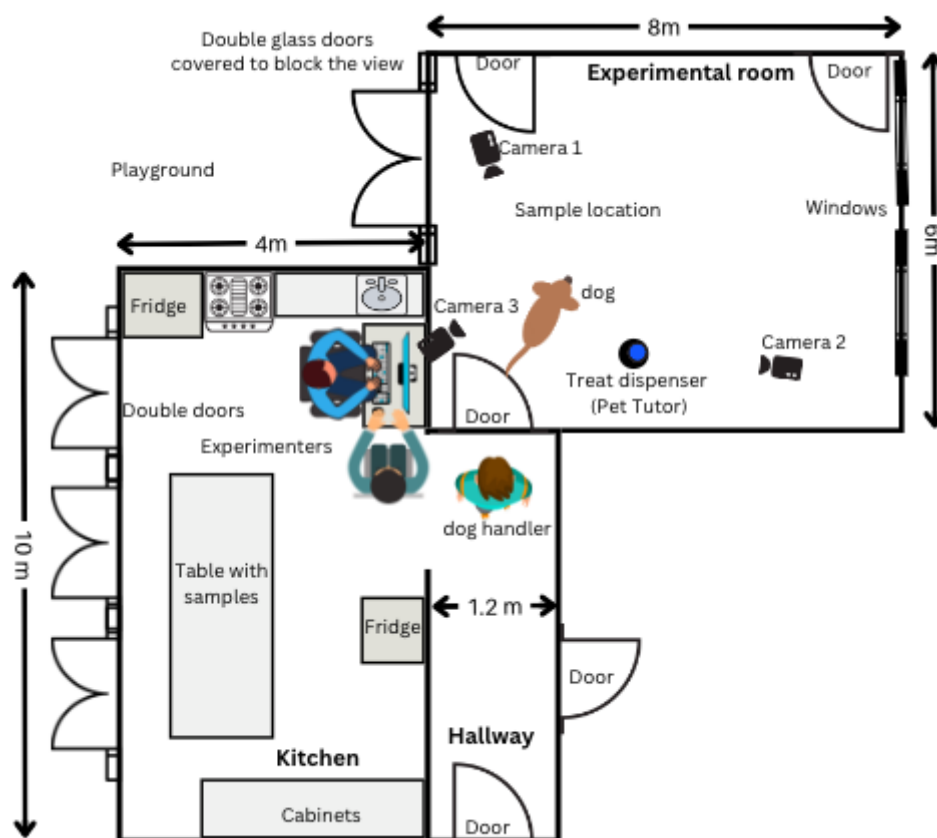


Figure 1. Experimental set up.

All dogs' responses were identifiable in real-time by the experimenter during the testing sessions and were later reviewed offline by the judge, who recorded each instance of correct and incorrect responses (e.g., Duranton et al., 2019).

2.2.1. Scent Box Training - Yes/No Proto

The choice of the yes/no procedure was supported by the work of Gadbois and Reeve (2016). The authors argue that multiple-alternative forced-choice tasks, such as line-up procedures with several choices, may misrepresent the accuracy of canines, as they rely on relative discrimination between stimuli. Instead, detection tasks like yes/no procedures provide a more robust and reliable measure of sensitivity in sensory detection and diagnosis since they indicate absolute identification/recognition of a stimulus. Indeed, the authors emphasize that the yes/no procedure allows for a solid assessment of performance and the ability to identify the specific type of errors made by the dogs, such as false alarms or misses. By utilizing this approach, the authors argue that

the yes/no procedure enables a more accurate assessment of the dog's detectability or discriminability.

The dogs learned through positive reinforcement to show a final trained response: "stand-stare" at the target odor. This method was based on classical and operant conditioning, as developed by B.F. Skinner (1938) and E. Thorndike (1898). Through successive approximations, the trainers marked any correct behavior with a clicker (a distinct noise maker) and gradually shaped the behavior until the dogs reliably stood and stared at the target odor for at least 3 consecutive seconds (final indication behavior). Incorrect responses received no reinforcement and were ignored. This behavior was trained as the dog signal for identifying SARS-CoV-2. A second behavior was taught for "Normal" samples: sitting. The dogs were presented with one sample at a time and trained to provide the corresponding behavior: "stand-stare" at a SARS-CoV-2 sample (AS and S), and "sit" in front of a Normal (N) sample.

The eight dogs were divided into two distinct training groups. The first group consisted of four dogs, trained exclusively with samples obtained from symptomatic (S) and healthy patients (N). The second group also comprised four dogs, trained solely with samples from asymptomatic (AS) and healthy patients (N). Furthermore, the dogs were evenly distributed between two training schools, ACADIA and ANIMALIN, with two dogs from each group being trained at each school. Specifically, two dogs from the asymptomatic group were trained at each school, along with two dogs from the symptomatic group. Note that one dog, Icare, from ANIMALIN school, was included in the pool of dogs three months later than the first three dogs, receiving only one month of training, while the seven others received four months of training. The training regimen involved exposing each dog to 20 normal (negative) SARS-CoV-2 samples and 10 SARS-CoV-2 (positive) samples of either symptomatic or asymptomatic Delta strain, to develop their detection capabilities (see Table 2).

Table 2. Repartition of type of stimuli according to the eight dogs.

	ANIMALIN					ACADIA		
	Blaike	Lina	Icare	Ramses	Ghost	Orco	Peps	Perle
N = 20	20	20	20	20	20	20	20	20
AS = 10	10	10			10	10		
S = 10			10	10			10	10

For both dog pools, the same human participants' scents were used. Characteristics of these participants are described in the Supplemental file, Part I.

For the training, samples were placed in 1 oz tin containers with holes in the lid, which were then placed inside larger containers (8 oz) also with lid holes. This setup ensured that direct contact between the dogs' noses and the samples was not possible. During training, a single container holding either a Normal or SARS-CoV-2 sample was placed on a plywood box measuring 30 cm in height, 20 cm in width, and 20 cm in depth. To ensure stability during investigation, a hole was cut at the top of the box, matching the diameter of the 8-oz container, so the container could be securely inserted without moving. Only one stimulus was presented at a time, and the dogs entered and then left the room after each training trial. They were trained to approach the box, sniff the container, and exhibit either a hold-stare response if the sample was a SARS-CoV-2 sample ("Yes") or a sit response if the sample was normal ("No"). To minimize human influence, the rewards were delivered through a remote-controlled treat dispenser (Pet Tutor). This allowed the trainer to remain outside the training room, eliminating any direct interaction. Training was considered successful when the dogs consistently displayed the appropriate behavior at least 80% of the time.

Although there were initial signs of progress and some dogs appeared to grasp the task, their performance remained inconsistent throughout the four months of training (one month for Icare), with fluctuations and unpredictable outcomes. The dogs struggled to provide consistent responses and faced difficulties in generalizing from the samples used during training. Achieving a consistent 80% accuracy proved to be challenging for most of the dogs.

All dogs were gathered at ACADIA to complete the learning phase. To familiarize the dogs with the experimental testing room, they were allowed ~5 min. minutes to explore it. Next, for a final training session, dogs were presented with the same 20 stimuli from the same participants used previously, but the third series of samples was used because series 1 and 2 of samples had been used extensively. Dogs showed inconsistent performance: while they displayed the correct behavior for some samples, in other cases, they appeared to respond randomly, and in some instances seemed to have memorized specific behaviors for specific samples. Overall, they were unable to achieve the required 80% performance criterion. The success rate ranged from 40% to 70%, falling below the desired learning threshold.

In light of these challenges, we decided to alter our training strategy and reintroduce the presentation of samples in a line format. While acknowledging that the line presentation may prompt the dogs to seek out salient odors rather than specific ones, and that recognition in this case is not absolute, it was considered appropriate to investigate the scientific questions above using both procedures and to discuss their respective strengths and limitations.

2.2.2. Discrimination Training - Line-Up Procedure

2.2.2.1. Material

Room and experimental setup

The same rooms and experimental setup were used in the previous protocol (see Figure 1). The line-up was placed in the same location as the single sample in the yes/no procedure. The video footage captured by the cameras was transmitted to a computer located in an adjacent room for observation and analysis.

One board (160 cm long x 13 cm wide X 2 cm thick) with six holes, each the same diameter as the sample containers (8 cm), was used for the line-ups. The samples were fitted tightly into the holes to ensure stability and avoid any shifting caused by the dogs' interaction. Six samples were evenly distributed: one SARS-CoV-2 (S or AS of Delta strain) sample and five normal (N) samples. The board was elevated at the same height as in the Yes/No setup and was placed on two boxes (30 cm x 20 cm x 20 cm), one at each end.

2.2.2.2. Procedure

Training

All dogs underwent a two-day re-training session with the samples presented in a line-up.

Each dog was individually introduced into the test room with no human present, and the door was securely closed behind them.

Each dog continued to be trained with either the AS or S samples from the third series of samples from the same participants they had previously been trained with; they were never exposed to the other type of COVID-19 samples. However, the Normal (N) samples were new to the dogs and also from the third series.

The samples were randomly selected and presented in sets of one COVID-19 sample (AS or S) and five Normal samples (see Supplemental file Part II for participant characteristics). Inside the room, dogs were free to explore the six-sample setup and sniff the containers. Once a dog located the target sample and exhibited the indication behavior (holding the nose over the sample - hold-stare), they were promptly rewarded using the Pet Tutor. The dog was then called out of the room. If the sample was not found within one minute, the dog was called out without a reward.

This procedure was repeated until all dogs reached the learning criterion of at least 80% success. Most dogs were able to reach an 80% success rate during two consecutive days of training. Only Icare did not meet the minimum required.

Baseline

On day three, the seven dogs were assessed in a baseline phase with the same samples they had been trained with, comprised of five trials. A total of five COVID-19 samples (S or AS) and ten Normal

samples were randomly selected and presented during this phase. The dogs were considered ready for testing since they successfully located the COVID-19 sample while ignoring the Normal samples, at least 80% of the time. The dogs were rewarded with the remote treat dispenser when finding the target samples.

For the baseline test, each dog completed five line-ups, each presenting six samples (five N and one AS or S), with the same set of 15 samples presented at random.

Each dog continued to be presented with either the AS or S samples from the third series of samples from the same participants they were previously trained with; again, they were never exposed to the other type of COVID-19 samples.

Test of samples

During the study, Omicron samples became available due to the evolution of the epidemic at the time of scent collection. The test phase was therefore divided into two parts.

Part 1 Delta: each dog participated in ten trials, with each trial consisting of a line-up of six samples. Across all trials, five S samples, five AS samples, and 25 Normal samples were used. Each line-up contained one COVID-19 (S or AS) sample and five Normal samples randomly selected and presented (see Supplemental file Part III participant characteristics). The same samples were used for all dogs. In this test, dogs were presented for the first time with samples from the category they had not previously trained on (either S or AS).

Part 2 Omicron (next day): Without any additional training, the dogs underwent five test trials similar to those for the Delta strain. Each trial included one Omicron AS sample and five Normal samples. The Omicron samples came from five different asymptomatic patients (see Supplemental file Part IV for participant characteristics). The Normal samples were randomly selected from the 25 Normal samples used in Part 1 (Delta). The samples were randomized for each dog.

All COVID-19 samples used in both tests were completely novel to the dogs, ensuring that they encountered unfamiliar scents compared with the learning and baseline phases, as well as throughout the trials.

3. Results

One out of seven dogs (i.e., Icare) did not reach the baseline learning criterion of 80% correct responses; he was therefore excluded from subsequent analysis. In each trial, only one out of the six cans contained the COVID-19 odor; hence, the chance sensitivity (the proportion of actual “positives” correctly identified) was 16.5%.

3.1. Delta Samples

Sensitivity ranged from 50% to 90% with an average of 71.4% (95% CI: 57.7–82.8%), significantly greater than chance: $p < .0001$ (Chi-squared). Specificity had an average of 50.7% (95% CI: 45.5–56.0%).

Three out of seven dogs reached 80% sensitivity, while four had lower performances, see Table 3).

Table 3. Correct response rate broken down by dog (Delta).

Dogs	Type	Sample size	Correct answers (%)	Sen*	P
BLAIKE	Asympto	60	28 (46.7%)	70%	0.0093
GHOST	Asympto	60	33 (55.0%)	50%	
LINA	Asympto	59	37 (62.7%)	90%	
ORCO	Asympto	60	39 (65.0%)	80%	
PEPS	Sympto	60	29 (48.3%)	70%	
PERLE	Sympto	60	22 (36.7%)	60%	
RAMSES	Sympto	60	39 (65.0%)	80%	
Tous (N=7)		419	227 (54.2%)	N/A	N/A

*Sensitivity calculated on 10 samples (10 patients).

3.2. Omicron Samples

Sensitivity ranged from 0% to 80% with an average of 54.9% (95% CI: 47.5 –62.2%), showing a trend towards significance ($p=0.0585$, Chi-square; Table 4). Specificity had an average of 54,9% (95% CI: 47,5-62,2%). Only one dog reached 80% sensitivity.

Table 4. Correct response rate broken down by dog (Omicron).

Chiens	Type	Nombre d'échantillons	Réponses Correctes (%)	Se*	P
BLAIKE	Asympto	30	13 (43.3%)	20.0%	0.0014
GHOST	Asympto	30	8 (26.7%)	40.0%	
LINA	Asympto	30	16 (53.3%)	0%	
ORCO	Asympto	30	25 (83.3%)	80.0%	
PEPS	Sympto	30	14 (46.7%)	0%	
PERLE	Sympto	30	13 (43.3%)	20%	
RAMSES	Sympto	30	17 (56.7%)	40%	
Tous (N=7)		210	106 (50.5%)	N/A	N/A

* Sensitivity calculated on 5 samples (5 patients).

3.3. Influence of the Training

Overall there was no significant difference in performances between the dogs trained with asymptomatic samples and those trained with symptomatic samples on Delta samples (sensitivities: 72.5% [57,7-82,8], $p<0,0001$, Chi-square, vs 70,0% [48,à-86,9], $p<0,0001$ (Chi-square)) $p=0,8188$ (Friedman with Bonferroni correction), respective specificities 54,3% [47,4-61,2] and 46,0% [38,0-54,0], $p=0,1265$ (Friedman test with Bonferonni correction).

On Omicron samples, dogs trained on asymptomatic samples showed slightly better performance (sensitivities:35.0% [13.5-62.2], $p=0.0422$, Chi-square, vs 20.0% [0.0-40.2], $p=0.3710$, Chi-square). However, no significant differences were detected ($p=0,3310$, Friedman test with Bonferroni correction). Given the small group sizes, these results may have been influenced by interindividual variability. Specificity was 55,0% [45,3-64,8] vs 54,7% [43,4-65,9] with no significant difference ($p=0,9651$, Friedman test with Bonferroni correction).

3.4. Influence of the Vaccination Status

For Delta samples, dog performance according to training type (S vs. AS) was not significantly different after adjustment for patients' vaccination status ($p = 0.8121$).

Among vaccinated patients, the sensitivity of dogs trained on asymptomatic patients was 81.3% [54.4–96.0] compared to 81.8% [48.2–97.7] for dogs trained on symptomatic patients (RR = 0.99 [0.69–1.43]).

Among non-vaccinated patients, the sensitivity of dogs trained on asymptomatic patients was 66.7% [44.7–84.4] compared to 70.6% [44.0–89.7] for dogs trained on symptomatic patients (RR = 0.94 [0.62–1.43]).

Similarly, the sensitivity of dogs to detect vaccinated patients was not significantly different from their sensitivity to detect non-vaccinated patients, after adjustment for training type ($p = 0.2339$).

3.5. Influence of the Symptomatic/Asymptomatic Status

For Delta samples, dog performance according to training type (S vs. AS) was not significantly different after adjustment for patients' vaccination status ($p = 0.8121$).

Among vaccinated patients, the sensitivity of dogs trained on asymptomatic patients was 81.3% [54.4–96.0], compared to 81.8% [48.2–97.7] for dogs trained on symptomatic patients (RR = 0.99 [0.69–1.43]).

Among unvaccinated patients, the sensitivity of dogs trained on asymptomatic patients was 66.7% [44.7–84.4], compared to 70.6% [44.0–89.7] for dogs trained on symptomatic patients (RR = 0.94 [0.62–1.43]).

Similarly, the sensitivity of dogs to detect vaccinated patients was not significantly different from their sensitivity to detect unvaccinated patients, after adjustment for training type ($p = 0.2339$).

4. Discussion

This study tested for the first time to our knowledge the hypothesis that dogs trained on symptomatic COVID-19 patients would detect asymptomatic cases with similar accuracy, and vice versa, and that performance might decline with newer viral variants such as Omicron. Our results supported the proof-of-concept approach: dogs trained on symptomatic patients successfully detected asymptomatic cases, and vice versa, for the Delta variant showing that asymptomatic patients can be detected by dogs. However, as predicted, detection performance dropped sharply with Omicron samples from vaccinated individuals, suggesting that variant-specific and host-related factors constrain the generalizability of canine detection.

In our study, the yes/no procedure proved less suited for COVID-19 detection than the line-up design. Discrimination in a single-sample presentation scenario proved challenging for several reasons: the lack of paired samples from the same individuals (both sick and healthy), the potential reinforcement of visual targeting rather than olfaction, and the possibility that the dogs memorized individual sample locations. Although the dogs had previously succeeded in training with other human scents, identifying COVID-19 samples was more difficult. This suggests that the scent signature of COVID-19 samples may not have been sufficiently salient or specific for reliable detection.

By contrast, the line-up procedure provided a more effective framework for this task. Presenting dogs with multiple samples simultaneously reduced the risk of location memorization and visual cueing, and allowed for relative discrimination of target vs. control odors. Under this protocol, dogs performed above chance when discriminating symptomatic and asymptomatic Delta samples, highlighting the importance of protocol selection in canine scent-detection studies.

This shift in approach aimed at addressing the limitations encountered during the previous protocol, focusing on aspects of training and memory.

The eight dogs underwent two days of training using the same set of samples, this time presented in a lineup format. Remarkably, all dogs quickly achieved a success rate above 90%. The baseline assessment thus revealed high success rates. In Test 1 (new Delta samples), six out of eight dogs succeeded while two did not. There was no discernible difference in performance between samples from symptomatic versus asymptomatic patients. In Test 2 (Omicron samples, all asymptomatic and vaccinated), only three dogs managed to locate a number of COVID-19 samples, resulting in a significant drop in overall performance.

In a lineup setup, dogs could compare the samples directly, without relying on a memorized odor, and promptly identify the most salient one. Trained dogs demonstrated the potential to achieve

high success rates with minimal training, consistent with other studies. This was true regardless of whether a patient had COVID-19 symptoms.

More than twenty studies have been published on the ability of scent detection dogs to detect COVID-19 (Meller et al., 2023). In this systematic review, high risks of bias and problems with applicability and/or quality were noted. Only four studies were assessed as low risk of bias, and six as high quality. The four unbiased QUADAS-2 studies reported sensitivity ranges of 81-97% and specificity ranges of 91-100%. The six high-quality studies, according to the overall assessment system, reported sensitivity ranges of 82-97% and specificity ranges of 83-100%. Performance in our study was lower than in the literature. However, most other studies focused exclusively on highly symptomatic patients with pulmonary symptoms and on variants prior to Omicron.

Our study was conducted at the end of the Delta wave and at the emergence of Omicron, when infection levels were extremely high. The kinetics of volatile compound emissions during SARS-CoV-2 infection remain completely unknown, as does the persistence of these compounds in the living spaces where samples were collected (hospital and home). Questions arise about the persistence of volatile compounds in the healthy population we selected (see Ozgur et al., 2023). Healthy individuals may not have developed symptoms of COVID-19 within seven days, but given the high incidence of the virus at that time, it is possible that some were asymptomatic COVID-19 carriers, which may have disrupted the odors detected by the dogs (InfoCovidFrance from 11/05/2020 to 30/06/2023). Longitudinal studies are needed to better estimate potential false negatives during an epidemic phase.

From an epidemiological standpoint, new COVID-19 variants with different symptom profiles, severity, and viral loads may require regular retraining of detection dogs with the currently circulating variant. When exposed to samples of a new variant (Omicron), none of the dogs reliably located the COVID-19 samples. This suggests that the olfactory signature was either too different from the previous one or undetectable. Omicron infections were generally milder, especially in the lungs, than Delta infections, which may have influenced volatile compound release (Relan et al., 2023; Mendiola-Pastrana et al., 2023).

Only one other study tested dogs with both the Delta and Omicron variants. Mutesa et al. (2022) reported a clear decrease in performance with Omicron compared to Delta. They also observed higher Ct values for the Omicron variant suggesting lower viral loads, which may partly explain the poorer detection rates.

Vaccination also appears to alter viral load dynamics, accelerating clearance and potentially modifying volatile compound production. Our findings also align closely with Ozgur et al. (2023), as dogs trained on Delta failed to reliably detect Omicron samples from vaccinated individuals, supporting the view that variant- and host-related factors can alter odor signatures and limit generalizability. In September 2021, half of the French population was fully vaccinated. Several studies reported reduced viral load and faster clearance in vaccinated individuals (Meller et al., 2023; InfoCovidFrance; Relan et al., 2023; Mendiola-Pastrana et al., 2023; Mutesa et al., 2022; Janes et al., 2024; Coppeta et al., 2021; Andeweg et al., 2025; Lunt et al., 2024; Woodbridge et al., 2022; Qassim et al., 2022). In our study, more than two-thirds of participants were vaccinated, which may have reduced the strength of volatile odor cues.

This study has several strengths. It was a randomized, double-blind, prospective design using a robust protocol: handlers were blinded, and the originally fully naïve dogs worked in a room without humans present. Eight dogs were trained with positive reinforcement, including two groups specifically trained with asymptomatic or symptomatic samples. Sample collection was standardized and performed by the same individual, and both home and hospital samples were represented across groups (symptomatic, asymptomatic, and controls), minimizing location bias. Importantly, all test samples were novel compared with training samples, and no scent lines were repeated, avoiding the artificial inflation of sensitivity sometimes seen in studies where dogs sniff the same samples multiple times. COVID-19 patients without respiratory symptoms were also included. Detailed, individual-level data were collected for each dog, further strengthening the reliability of the study.

Nevertheless, some limitations should be acknowledged. The dogs were relatively inexperienced (“green”), unlike other studies that relied on highly trained explosives-detection dogs. The protocol was also modified mid-study, moving from a yes/no to a line-up procedure, which may have introduced variability in training history, but also a pre-history in detecting COVID-19 scent. Finally, the number of Omicron samples, particularly from vaccinated individuals, was limited, constraining the power to fully evaluate generalization across variants.

5. Conclusion

This study provides the first controlled evidence that dogs trained on symptomatic COVID-19 patients can detect asymptomatic cases, and vice versa, at least for the Delta variant and in a line up protocol. However, performance collapsed with Omicron samples from vaccinated individuals, highlighting the dependence of canine detection on viral variant and host immune status.

These findings underline both the potential and the limitations of medical detection dogs in infectious disease surveillance. Dogs can generalize across symptom status under controlled conditions, but their reliability is compromised by evolving viral biology and population-level vaccination. Future research should focus on (1) standardizing protocols, (2) clarifying the biological origin of VOC signatures, and (3) assessing whether frequent retraining with circulating variants can sustain diagnostic accuracy. Until such evidence is available, canine detection should be considered exploratory and not a substitute for conventional testing in public health contexts of infection diseases.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

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References

- Aksenov, A.A, Sandrock, C.E, Zhao, W., ... & Davis. (2014). Cellular scent of influenza virus infection. *Chembiochem*, 15(7):1040-1048. <https://doi.org/10.1002/cbic.201300695>
- Andeweg, S.P., van de Kasstele J., Wang, X., ... & Eggink, D. (2025). Estimating the effect of COVID-19 vaccination and prior infection on cycle threshold values as a proxy of SARS-CoV-2 viral load. *International Journal of Infectious Diseases*, 153:107362. <https://doi.org/10.1016/j.ijid.2024.107362>
- Angle, T.C., Passler, T., Waggoner, P.L., Fischer, T. D., Rogers, B., & Galik, P. K. (2015). Real-time detection of a virus using detection dogs. *Frontiers in Veterinary Science*, 2:79. <https://doi.org/10.3389/fvets.2015.00079>
- Bauër, P., Leemans, M., Audureau, E., Gilbert, C., Armal, C., & Fromantin, I. (2022). Remote medical scent detection of cancer and infectious diseases with dogs and rats: a systematic review. *Integrative Cancer Therapies*, 21, 15347354221140516. <https://doi.org/10.1177/15347354221140516>

- Bax, C., Robbiani, S., Zannin, E., Capelli, L., Ratti, C., Bonetti, S., et al. & Dellacà, R. L. (2022). An experimental apparatus for e-nose breath analysis in respiratory failure patients. *Diagnostics*, 12(4), 776. <https://doi.org/10.3390/diagnostics12040776>
- Catala, A., Grandgeorge, M., Schaff, J. L., Cousillas, H., Hausberger, M., & Cattet, J. (2019). Dogs demonstrate the existence of an epileptic seizure odour in humans. *Scientific reports*, 9(1), 4103. <https://doi.org/10.1038/s41598-019-40721-4>
- Coppeta, L., Balbi, O., Grattagliano, Z., Mina, G.G., Pietroiusti, A., Magrini, A., ... & Trabucco Aurilio, M. (2021). First dose of the BNT162b2 mRNA COVID-19 vaccine reduces symptom duration and viral clearance in healthcare workers. *Vaccines (Basel)*, 17;9(6):659. <https://doi.org/10.3390/vaccines9060659>
- Duranton, C., Bedossa, T., & Gaunet, F. (2019). Pet dogs exhibit social preference for people who synchronize with them: what does it tell us about the evolution of behavioral synchronization? *Animal cognition*, 22(2), 243-250. <https://doi.org/10.1007/s10071-019-01241-w>
- Gadbois, S., & Reeve, C. (2014). Canine olfaction: scent, sign, and situation. In *Domestic dog cognition and behavior: The scientific study of Canis familiaris* (pp. 3-29). Berlin, Heidelberg: Springer berlin heidelberg.
- Gadbois, S., & Reeve, C. (2016). The semiotic canine: scent processing dogs as research assistants in biomedical and environmental research. *Dog behavior*, 2(3), 26-32. <https://doi.org/10.4454/db.v2i3.43>
- Grizzi, F., Bax, C., Farina, F. M., Tidu, L., Hegazi, M. A., Chiriva-Internati, M., ... & Taverna, G. (2024). Recapitulating COVID-19 detection methods: RT-PCR, sniffer dogs and electronic nose. *Diagnostic Microbiology and Infectious Disease*, 110(1), 116430. <https://doi.org/10.1016/j.diagmicrobio.2024.116430>
- Grandjean, D., Elie, C., Gallet, C., Julien, C., Roger, V., Desquilbet, L., ... & Treluyer, J. M. (2022). Diagnostic accuracy of non-invasive detection of SARS-CoV-2 infection by canine olfaction. *PLoS One*, 17(6), e0268382. <https://doi.org/10.1371/journal.pone.0268382>
- Guest, C., Pinder, M., Doggett, M., Squires, C., Affara, M., Kandeh, B., ... & Lindsay, S. W. (2019). Trained dogs identify people with malaria parasites by their odour. *The Lancet Infectious Diseases*, 19(6), 578-580. [https://doi.org/10.1016/S1473-3099\(19\)30220-8](https://doi.org/10.1016/S1473-3099(19)30220-8)
- Guest, C., Dewhirst, S. Y., Allen, D. J., Aziz, S., Baerenbold, O., & Bradley, J. (2022). Using trained dogs and organic semi-conducting sensors to identify asymptomatic and mild SARS-CoV-2 infections. *Journal of Travel Medicine*, 29 (3), p. taac043 <https://doi.org/10.1093/jtm/taac043>
- Halfon, P., Penaranda, G., Khiri, H., Garcia, V., Drouet, H., Philibert, P., Psomas, C., Delord, M., Retornaz, F... & Allardet-Servent, J. (2021). An optimized stepwise algorithm combining rapid antigen and RT-qPCR for screening of COVID-19 patients. *PLoS One*, 16(9), e0257817. <https://doi.org/10.1371/journal.pone.0257817>
- Hardin, D. S., Anderson, W., & Cattet, J. (2015). Dogs can be successfully trained to alert to hypoglycemia samples from patients with type 1 diabetes. *Diabetes Therapy*, 6, 509-517. <https://doi.org/10.1007/s13300-015-0135-x>
- Janes, H., Fisher, L. H., Kee, J. J., Parameswaran, L., Goepfert, P. A., Falsey, A. R., ... & Huang, Y. (2024). Association between SARS-CoV-2 viral load and COVID-19 vaccination in 4 phase 3 trials. *Journal of Infectious Diseases*, 16;230(6):1384-1389. <https://doi.org/10.1093/infdis/jiae40>
- Lunt, R., Quinot, C., Kirsebom, F., Andrews, N., Skarnes, C., Letley, L. et al. The impact of vaccination and SARS-CoV-2 variants on the virological response to SARS-CoV-2 infections during the Alpha, Delta, and Omicron waves in England. *Journal of Infection*, 88(1):21-29. <https://doi.org/10.1016/j.jinf.2023.10.016>
- Meller, S., Caraguel, C., Twele, F., Charalambous, M., Schoneberg, C., Chaber, A.L., Desquilbet, L., Grandjean, D., Mardones, F.O., Kreienbrock, L., de la Rocque, S., Volk H.A. (2023) Canine olfactory detection of SARS-CoV-2-infected humans-a systematic review. *Annual Epidemiology*, 85:68-85. <https://doi.org/10.1016/j.annepidem.2023.05.002>
- Mendiola-Pastrana, I.R., López-Ortiz, E., Río de la Loza-Zamora, J.G., González, J., Gómez-García, A., López-Ortiz, G. (2022). SARS-CoV-2 variants and clinical outcomes: A systematic review. *Life (Basel)*, 12(2):170. <https://doi.org/10.3390/life12020170>
- Mutesa, L., Misbah, G., Remera, E., Ebberts, H., Schalke, E., Tuyisenge, P., ... & Nsanzimana, S. (2022). Use of trained scent dogs for detection of COVID-19 and evidence of cost-saving. *Frontiers in Medicine*, 1;9:1006315. <https://doi.org/10.3389/fmed.2022.1006315>

- Otto, C. M., Sell, T. K., Veenema, T. G., Hosangadi, D., Vahey, R. A., Connell, N. D., & Privor-Dumm, L. (2023). The promise of disease detection dogs in pandemic response: lessons learned from COVID-19. *Disaster medicine and public health preparedness*, 17, e20. <https://doi.org/10.1017/dmp.2021.183>
- Ozgun-Buyukatalay, E., Demirbas, Y. S., Bozdayi, G., Kismali, G., & Ilhan, M. N. (2023). Is diagnostic performance of SARS-CoV-2 detection dogs reduced-due to virus variation-over the time? *Applied Animal Behaviour Science*, 258, 105825 <https://doi.org/10.1016/j.applanim.2022.105825>
- Qassim, S. H., Hasan, M. R., Tang, P., Chemaitelly, H., Ayoub, H. H., Yassine, H. M., ... & Abu-Raddad, L. J. (2022). Effects of SARS-CoV-2 Alpha, Beta, and Delta variants, age, vaccination, and prior infection on infectiousness of SARS-CoV-2 infections. *Frontiers in Immunology*, 13, 984784. <https://doi.org/10.3389/fimmu.2022.984784>
- Reeve, C., Wilson, C., Hanna, D., & Gadbois, S. (2021). Dog Owners' Survey reveals Medical Alert Dogs can alert to multiple conditions and multiple people. *PLoS One*, 16(4), e0249191. <https://doi.org/10.1371/journal.pone.0249191>
- Relan, P., Motaze, N. V., Kothari, K., Askie, L., de Waroux, O. L. P., Van Kerkhove, M. D., ... & Vijayaraghavan, B. K. T. (2023). Severity and outcomes of Omicron variant of SARS-CoV-2 compared to Delta variant and severity of Omicron sublineages: a systematic review and metanalysis. *BMJ Global Health*, 8(7). <https://doi.org/10.1136/bmjgh-2023-012328>
- InfoCovidFrance on Santé Public France <https://www.santepubliquefrance.fr/dossiers/coronavirus-covid-19/coronavirus-chiffres-cles-et-evolution-de-la-covid-19-en-france-et-dans-le-monde> Retrieved 31th of october.
- Ungar, P. J., Pellin, M. A., & Malone, L. A. (2023). A One Health perspective: COVID-sniffing dogs can be effective and efficient as public health guardians. *Journal of the American Veterinary Medical Association*, 262(1), 13-16. <https://doi.org/10.2460/javma.23.10.0550>
- Van Doremalen, N., Bushmaker, T., Morris, D. H., Holbrook, M. G., Gamble, A., Williamson, B. N., ... & Munster, V. J. (2020). Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *New England journal of medicine*, 382(16), 1564-1567. <https://doi.org/10.1056/NEJMc2004973>
- Woodbridge, Y., Amit, S., Huppert, A., & Kopelman, N. M. (2022). Viral load dynamics of SARS-CoV-2 Delta and Omicron variants following multiple vaccine doses and previous infection. *Nature Communications*, 13(1), 6706 <https://doi.org/10.1038/s41467-022-33096-0>

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