Is COVID-19 associated with self-reported audio-vestibular symptoms?

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Abstract

Objective: To determine if a positive test for COVID-19 is associated with self-reported audio-vestibular symptoms.

Design: Self-reported changes in hearing, tinnitus, hyperacusis, and dizziness/rotatory vertigo were assessed in hospitalised and non-hospitalised COVID-19 patients *during* and *after* the acute phase of the disease and compared to non-COVID controls.

Study sample: There were 150 severe cases of COVID-19 requiring hospital admission and 150 mild cases that were managed at home. Controls were 267 adults, 32 of whom had been hospitalised for a non-COVID-19 condition, and a further 85 who worked in hospital settings.

Results: Deterioration in hearing and/or tinnitus was reported in 8% of the COVID-19 cases (tinnitus had resolved in 2% after the acute phase), with no significant difference between severe and mild cases. Deterioration in hearing or tinnitus was not significantly different from controls. However, rotatory vertigo was reported by 5% in the COVID-19 groups and 1.1% in the controls, and this difference was statistically significant.

Conclusions: There is no evidence that COVID-19 results in deterioration in hearing or tinnitus during the acute phase or after recovery in mild or severe cases. However, rotatory vertigo, which could be vestibular in origin, may be a clinical manifestation of COVID-19.

Keywords

Audio-vestibular, COVID-19, Self-reported, Hearing loss, Tinnitus, Rotatory Vertigo.

Introduction

The SARS-CoV-2 virus, the cause of COVID-19, is part of a larger family of coronaviruses that may cause illness in animals and humans, e.g., Middle East Respiratory Syndrome (MERS) and Severe Acute Respiratory Syndrome (SARS) [1]. It is well documented that viral infections may cause hearing loss [2]. Given the reported central and peripheral nervous system manifestations in COVID-19 cases [3, 4] , it is reasonable to assume that neuropathic complications involving the auditory nerve may also occur. Hence, an auditory and/or a vestibular component to sensory symptoms may also occur in some COVID-19 cases.

The first systematic review on coronaviruses and the audio-vestibular system was published in June 2020 [5]. The authors noted a lack of reports of audio-vestibular symptoms associated with earlier types of coronavirus (i.e., SARS and MERS), whereas a few audio-vestibular symptoms such as hearing loss, tinnitus and vertigo have been reported in individuals who tested positive for COVID-19. The review was since been updated [6] and there are now more than 58 studies that have investigated audio-vestibular symptoms in COVID-19. There are multiple reports of audio-vestibular symptoms associated with COVID-19. Half of these studies are case reports/series and the remaining studies are cross-sectional, frequently involving self-report surveys with no control groups; however, some used clinical tests [7-9]. The pooled estimate of prevalence was reported as 7.6%, 14.8%, and 7.2%, for hearing loss, tinnitus and rotatory vertigo, respectively. However, the authors highlighted the need for caution because: 1) it was not always clear if studies were reporting a change in pre-existing audio-vestibular symptoms or transient symptoms that resolved after recovery from the acute phase of COVID-19; and 2) some of the studies combined the prevalence of vertigo with dizziness or used the two terms interchangeably, although

dizziness is not necessarily of vestibular origin. In addition, the lack of appropriate control groups is a significant limitation in the existing literature.

There is an urgent need for studies that specifically investigate a change in audio-vestibular symptoms, relative to pre-COVID-19, and that compare the findings against appropriate control groups. Therefore, the aim of the present study was to investigate self-reported audio-vestibular symptoms in individuals testing positive for COVID-19. Specific attention was given to:

1) Using a direct measure of change in audio-vestibular symptoms, relative to pre-COVID-19 baseline;
2) Comparing audio-vestibular symptoms during both the acute phase and after recovery from COVID-19;
3) Including a group of mild COVID-19 symptoms, managed at home, and a second group of severe symptoms that required hospitalisation;
4) Including control groups of non-COVID-19 cases for comparison; and
5) Assessing self-reported changes in smell and taste using the same scale as for the audio-vestibular symptoms, since loss of smell and taste are recognised neurological symptoms of COVID-19. This would determine if any hearing difficulties are consistent with a general neuropathy.

Methods

Participants

The sample size was calculated based on an assumed prevalence of hearing loss of 10%. A sample size of 139 participants per group was suggested to provide a statistical power of 0.8 for a two-tailed prediction and an alpha of 0.05 to detect a difference between the two groups (online statistical calculator [10]). Therefore, we planned to collect data from 150

patients for each group to allow for drop-out. Data collection occurred between 15 July and 15 November, 2020. Participants did not receive payment. The study was approved by the Central Institutional Review Board, Ministry of Health Kingdom of Saudi Arabia (IRB reference number: 20-140E- Public Health Research and Health Statistics, Saudi Center for Disease Control and Prevention [SCDC] Registration number: 20200720) and the Institutional Review Board, College of Medicine, King Saud University (Reference Number 20/0610/IRB).

COVID-19 groups (test groups)

The test groups comprised a total of 300 participants. One hundred and fifty participants (mean age 44.2 years, range 19-65 years; 90 males) were admitted to the hospital during illness (COVID-Hosp), and 150 participants (mean age 35.9 years, range 18-64 years; 66 males) were home isolated (COVID-Home) during the time they exhibited COVID-19 symptoms. Inclusion criteria for the test groups were those between 18-65 years of age who had recovered from a confirmed diagnosis and had experienced at least one of the common symptoms of COVID-19. Reverse Transcription Polymerase Chain Reaction (RT-PCR) (i.e., nasopharyngeal or oropharyngeal swabs) provided diagnostic testing for confirmation of COVID-19.

The test groups (COVID-Hosp and COVID-Home) were recruited collaboratively with the Ministry of Health and King Khalid University Hospital in Riyadh, Kingdom of Saudi Arabia. The researchers were given access to contact details (phone numbers) of a random sample of COVID-19 cases, so data included the date of confirmation of diagnosis, age, sex, nationality, and whether the participant was hospitalised or home-quarantined.

Control groups

Rationale and limitations

We aimed to control for changes due to the following: 1) effects of retrospective versus current reporting (recall bias); 2) consequences of anxiety of hospital admission; and 3) changes from environmental and psychological pandemic-related factors.

Hence, the initial recruitment plan was to create two non-COVID-19 control groups:

1) Participants who had not been hospitalised in the four months prior to taking part in this study, were at home during lockdown, and were back to work or socialising with restrictions at the time of the interviews (Control-Home); and
2) Participants who had been hospitalised for a condition we do not believe affects hearing (Control-Hospitalised patients).

While Control-Hospitalised patients would have been the ideal group for matching to COVID-Hosp cases, due to limited admissions as a result of COVID-19 policies, recruiting with this criterion was difficult. Therefore, we decided to form two subgroups within the Control-Hosp group to control for communication in the hospital environments: Control-Hospitalised patients and Control-Healthcare professionals. This is an evident limitation, and sub-group analysis was applied to investigate if bias appears in the findings.

Sample

The final control groups comprised 267 participants between 18-65 years of age who have never been diagnosed with (nor were suspected to have) COVID-19; 150 participants in Control-Home (mean age 37.2 years; age range 18-65 years; 65 males) and 117 participants in Control-Hosp. The Control-Hosp group included two subgroups: 32 recently discharged patients (interviewed within the first week after discharge), and 85 healthcare professionals who had worked in hospitals during the pandemic until the time of the interview (mean age 36.6 years; age range 22-57 years; 63 males). Emails and WhatsApp messages to potential participants invited them to participate as study controls and to agree to a phone interview.

They were also asked to forward the invitation to other members of the general public whom they believed fit the control group's criteria.

Since we were interested in any noticeable change, there was no need to exclude any participants (test or control) with pre-existing audio-vestibular symptoms (see Table SM1 in Supplementary Materials for the participant details).

Measures and procedure

For the test groups

The questionnaire contained two main sections, using the same basic questions to assess changes in symptoms (see questionnaire content below for detailed description). The main section was repeated to assess changes over time (i.e., comparing *during-to-before* symptoms of COVID-19, and comparing *current-to-during* symptoms of COVID-19), thereby estimating the change in symptoms between before, during and after illness times. (See Supplementary Materials for the English version of the test group questionnaire.)

The range of the '*during COVID-19'* phase in the present study was defined as up to 14 days from the first noticeable symptoms (for the COVID-Home), although this period could extend beyond 14 days for the hospitalised, as it continued until discharge from hospital for COVID-Hosp.

Interviews took place between 21-60 days after recovery for the test groups. Recovery was defined as resolution of fever (if present) without fever-reducing medications, improvement in respiratory symptoms (e.g., cough, shortness of breath), and at least 14 days since symptoms first appeared. Thus, the *after-recovery* phase range was between 5-12 weeks from the first noticeable symptoms.

For the control groups

The control group questionnaire contained one main section using the same basic questions to assess any experienced change at the time of the interview compared to before the pandemic (i.e., retrospective at one timepoint from April 2020 to the time of questionnaire).

Initially, data collection was planned via online questionnaires. However, the test group response rate to the online questionnaires was low: participants preferred to complete the questionnaire through phone calls. Thus, online responses were excluded from the analysis and all data were collected (for test and control groups) via phone interviews to avoid the risk of biased responses from using different methods for test and control groups..

Questionnaire

Development and validity

Author AJ developed the first version of the questionnaire and revised it based on feedback from author CP. This revised questionnaire was translated into Arabic to be available in both Arabic and English in respect of each participant's preferred language. The face validity of these two revised versions was assessed by a sub-group of 15 participants (nine from controls: six Arabic and three English native speakers; and six from test groups: four Arabic and two English native speakers) all without medical backgrounds. Once participants agreed on clear wording and relevance of questions, the two versions were accepted for data collection. This was intended as an internal pilot which we initially included in the study. However, as these responses were collected via online questionnaires, they were excluded from the final analysis.

Content

The questionnaire consisted of two main sections.

A. Demographics, health status and hearing-related items

For both the control and test groups, the questionnaire opened with a section for participant demographics and health status.

This was followed by an investigation of the existence of any audio-vestibular symptoms prior to the COVID-19 pandemic, including hearing loss (subjective or with a confirmed diagnosis), wearing hearing aids, tinnitus, ear operations/problems and rotatory vertigo. This information was elicited with yes/no screening questions.

In the test group questionnaire, an additional part assessed for symptoms experienced during the time they had COVID-19.

B. The main section of the questionnaire

The main section was designed with a five-point Likert scale to assess any self-reported change over time in nine symptoms under four categories.

1) **Olfactory and gustatory abnormalities** which included disturbances in *sense of smell* and *taste*.
2) **Auditory symptoms** which included *hearing abilities* (changes assessed for four variables: sense of hearing, ease of conversing by telephone, ability to follow a conversation with background noise, and preferred volume while listening to various media); *non-pulsatile tinnitus*; and *hyperacusis* (i.e., stress, irritation or sensitivity caused by noise and environmental sounds).
3) **Dizziness** which included *rotatory vertigo* (the feeling that the person, or things around person, are spinning or moving); and *stability* (unsteadiness/light-headedness, losing balance or feeling unsteady when walking, climbing stairs, or picking something up off the floor).
4) **Ear symptoms** which included *ear pressure*; and *otalgia* (ear pain).

Statistical analyses

In order to make comparisons of the distribution of the categorical variables between the different groups, Fisher's exact test and chi-square test were performed. For these tests, two-side *p*-values determined whether the distribution of the variables was significantly different between the groups. Correction was applied to the alpha criterion to compensate for multiple comparisons using the Holm-Bonferroni method. A significant difference between the two groups was considered when the *p*-value remained significant after the correction. Chi-square analysis was used to investigate the relationship between symptoms. Valid statistical comparisons between the groups were not always possible due to the low number of patients reporting the experience of some of the examined symptoms. Reported *p*-values from this study should be interpreted with caution, especially for symptoms where fewer than five patients reported having experienced them. SAS (Version 9.3, SAS institute) was used to calculate these values.

Results

Demographic and pre-existing health characteristics

The COVID-Hosp group had a significantly higher mean age than the Control-Home. Table SM1 in Supplementary Materials summarises demographic and pre-existing health characteristics.

General symptoms of COVID-19

Figure 1 shows the distribution of common symptoms experienced by the COVID-19 participants during the acute phase (panel A) and the first noticed symptoms (panel B). As expected, there was greater respiratory illness and difficulty breathing in the COVID-Hosp group. See Table SM2 in Supplementary Materials for the comparison between COVID-19 symptoms, during the acute phase, in severe and mild COVID-19 cases.

******Insert Figure 1 about here******

Changes in symptoms

Table 1 shows the percentages and number of cases of those who self-reported any change across the nine symptoms assessed in the questionnaire. For the two COVID-19 groups, these numbers give an estimation of the reported changes in symptoms *during* and *after* the acute phase of the disease, relative to pre-COVID-19 baseline. However, for the control groups, based on the collected data (i.e., retrospective at one timepoint from April 2020 to time of questionnaire), only percentages are provided of the total number of cases who self-reported any change at the time of the interview compared to before the pandemic. Changes in symptoms for the Control-Hosp sub-groups (i.e. Control-Hospitalised patients and Control-Healthcare professionals) are also reported.

Figure 2 shows changes in smell or taste (panel A) and audio-vestibular symptoms (panel B) among the COVID-19 and control groups (and sub-groups). For the COVID-19 groups, these represent the percentages of those who reported deterioration in symptoms during or after illness. Table 2 presents the results of comparisons (and sub-group analysis) between the COVID-19 and control groups for the symptoms reported in Table 1.

******Insert Table 1 about here******

******Insert Figure 2 about here******

******Insert Table 2 about here******

1) ***Olfactory and gustatory abnormalities***

Unlike the controls, changes in smell and taste were frequently reported by the COVID-19 groups. Changes in smell and taste, if experienced, resolved or at least improved for most participants.

2) ***Auditory symptoms***

In the COVID-19 groups, the total numbers of participants who reported any deterioration in hearing and/or tinnitus at some timepoint since being diagnosed were identical: 12 (8%) for the COVID-Hosp group and 12 (8%) for the COVID-Home group. For the control groups, eight (6.8%) in Control-Hosp, one (3.1%) in the Control-Hospitalised patient sub-group, seven (8.2%) in the Control-Healthcare professional sub-group, and eight (5.3%) in Control-Home reported changes in hearing and/or tinnitus at the time of the interview compared to before the pandemic. The number of cases who self-reported recent changes in *both* hearing and tinnitus was three (2%) COVID-Hosp, one (0.9%) Control-Hosp, one (0.7%) COVID-Home and one (0.7 %) Control-Home. No association was found between self-reported changes in auditory symptoms and changes in smell or taste.

Seven (4.7%) in COVID-Hosp and six (4%) in COVID-Home reported deterioration in hearing at a point post-COVID-19 diagnosis (Table 1). None of these participants reported resolved hearing loss at the time of the interview. There was no significant difference between the two COVID-19 groups, nor between COVID-19 groups and controls, in the number of cases reporting hearing deterioration (Table 2).

Changes in tinnitus were reported by eight (5.3 %) COVID-Hosp and seven (4.7 %) COVID-Home cases. Two (1.3%) and four (2.7%) participants reported that the tinnitus had resolved after the acute phase in the COVID-Hosp and COVID-Home groups, respectively (Table 1). There was no significant difference between the two COVID-19 groups, nor between COVID-19 groups and controls, in the number of cases reporting changes in tinnitus (Table 2).

Self-reported recent changes in sensitivity to sounds (hyperacusis) were rarely reported (Table1).

Table SM4 in Supplementary Materials presents the characteristics of those in the test and control groups and sub-groups who self-reported change in hearing, tinnitus or vertigo.

These characteristics included age and sex, and pre-existing hearing loss (subjective or with a confirmed diagnosis), tinnitus, or vestibular symptoms. Performing valid statistical comparisons between these characteristics across the groups was not possible due to the low number of patients who reported having experienced these symptoms (in some cases, just one participant).

The number of those who reported the onset of tinnitus was higher in COVID-Home (five out of seven [71.4%]) than in Control-Home (one out of six [16.6%]; $p = 0.048$). In the Control-Home group, the majority (five out of six [83.3%]) reported a worsening of pre-existing tinnitus during the pandemic.

3) ***Dizziness***

Unsteadiness/light-headedness

Fifty-three cases (17.7%) reported experiencing unsteadiness or light-headedness at some point since COVID-19 diagnosis (34 [22.7%] COVID-Hosp and 19 [12.7%] COVID-Home, Table 1). Those with COVID-19 who were hospitalised were more likely to report unsteadiness/light-headedness compared to those who were not hospitalised ($p = 0.033$), however, this difference did not remain significant following correction. A significant difference was found between COVID-19 and control groups (Table 2).

Rotatory vertigo

Fifteen cases (5%) reported experiencing rotatory vertigo at some point since COVID-19 diagnosis (six [4%] COVID-Hosp and nine [6%] COVID-Home), with no statistically significant difference between the two COVID-19 groups. Three participants (1.1%) in the controls reported changes in vertigo (Table 1). A difference was found in the number of cases who reported rotatory vertigo symptoms between COVID-19 and control

groups (p = 0.008), however, this did not remain significant following Holm-Bonferroni correction (Table 2).

As age was not well matched between the test and control groups (COVID-Hosp were significantly older than Control-Hosp), logistic regression modelling was performed to test whether reporting vertigo was associated with whether a person had COVID-19 while controlling for age as a covariate. A significant difference was found in the number of cases who reported vertigo between COVID-19 and control groups (i.e., those with COVID-19 were significantly more likely to report vertigo while controlling for age) (Z = 2.69, p = 0.008). Age was also significantly associated with a *reduced* likelihood of reporting vertigo (Z=-2.49, p=0.013).

In addition, we tested for the partial effect of having COVID-19 on reporting vertigo while controlling for hospitalisation (or working in hospital) and age. In this model the partial effect of having COVID-19 while controlling for both remained significantly associated with experiencing vertigo (Z = 2.67, p = 0.008). Specifically, having COVID-19 was associated with being 5.61 times more likely to report vertigo than not (OR = 5.61, 95% CI = 1.58 – 19.91). However, the partial effect of hospitalisation, while controlling for COVID-19 and age, was not associated with vertigo (Z = 0.511, p = 0.609).

There was a significant difference (p = 0.003) in the number of participants who reported experiencing vertigo for the first time (i.e., onset) between the COVID-19 and controls. None of the controls reported experiencing vertigo for the first time during the pandemic, and only described the change as a worsening of a pre-existing symptom, while the majority (93.3%) of those from COVID-19 groups who self-reported vertigo had no pre-existing vestibular symptoms (Table SM4). Those participants believed that this was linked to COVID-19.

Dizziness and COVID-19 severity

A relation was found between the presence of respiratory difficulties and self-reported worsening in stability in the COVID-19 groups ($p = 0.004$ for COVID-Hosp and $p = 0.002$ for COVID-Home). However, no significant relation was found between self-reported rotatory vertigo and respiratory difficulties.

The majority of cases who self-reported experiencing unsteadiness or light-headedness during the acute phase had recovered fully by the time of the interview (80% COVID-Hosp and 74% COVID-Home). However, with respect to rotatory vertigo, the majority reported persistent vertigo at the time of the interview (83% in COVID-Hosp and 77.7% in COVID-Home). No association was found between self-reported dizziness and changes in smell or taste.

4) ***Ear symptoms***

Self-reported ear pressure and otalgia

Only two participants (1.3%) COVID-Hosp and five (3.3%) COVID-Home self-reported ear fullness), with no differences between the groups (Table 2). Ear pain was the least commonly reported among all reported symptoms (Table 1).

Discussion

In keeping with the recent literature on COVID-19 symptoms, the present data strongly support previous findings that abnormalities in smell and taste are directly related to COVID-19. The number of cases reporting noticeable changes in auditory symptoms was small, and not statistically different between COVID-19 and control groups. Ear pressure and pain were rarely reported by COVID-19 participants. However, self-reports of dizziness and vertigo were significantly higher among the COVID-19 groups compared to controls.

Is COVID-19 associated with auditory symptoms?

The data provide no clear evidence that patients who have been diagnosed with COVID-19 are more likely to self-report deterioration in hearing, tinnitus, or hyperacusis. A trend showed that those who have had COVID-19 were more likely to develop tinnitus, with no history of pre-existing symptoms. A few COVID-19 participants who reported deterioration in hearing and/or tinnitus noticed this more in one ear (unilateral), however, as the questionnaire did not include questions that differentiated between bilateral and unilateral symptoms, this was not systematically investigated.

These results suggest that either no direct effect of COVID-19 on hearing abilities exists, or that the prevalence is relatively low. However, given the infection rates with SARS-CoV-2, even hearing problems in only a small percentage of people would translate into a significant number of people affected across the entire population, posing a major health concern.

The findings of the present study challenge the results of many previous studies which have reported auditory symptoms associated with COVID-19. Our results contradict those reviewed in an updated systematic review [6] (whether using self-reported measures with no controls or clinical tests with no sufficient details about the control groups [9]), and those of the recently published study of de Sousa et al. (2021) [11] that have used clinical tests but compared the results to an inappropriate control group. de Sousa et al. (2021) compared the pure tone audiograms of hospitalised moderate to severe COVID-19 patients with comorbidities and those who had oxygen delivery by nasal cannula while performing the hearing test, with controls from the general population who were clinically stable and not hospitalised. The noise levels while performing audiometry were relatively high and no effort to keep the noise level constant across the two groups was reported.

The present findings support the conclusion of the recently published study of Gallus et al. (2021) [12], suggesting no clear evidence of persistent hearing loss or clinically relevant

cochlear damage in recovered COVID-19 patients. Gallus et al. (2021) used a clinical screening protocol (i.e., pure tone audiometry) as well as self-reported symptoms, and compared the results with age- and sex-matched controls from the same population.

A possible explanation for the self-reports of tinnitus or deterioration in hearing is that these effects are due to the environment and COVID-19 restrictions on ease of communication, levels of stress, and social isolation and lockdown. Face masks have a negative impact on hearing[13], increase anxiety and stress, and make communication fatiguing, especially in medical situations and for the hearing impaired [14]. In the COVID-Home group, 66.6% of those who reported deterioration in hearing after recovery from COVID-19 mentioned that these symptoms were realised and worsened 'after going back to work or when socialising with background noise.' This suggests that, even if there was an effect of the virus, restrictions may heighten the awareness of pre-existing hearing difficulties which may then be perceived as hearing deterioration. Moreover, the language of the medical system in Saudi Arabia is English, which is not a first language for most healthcare professionals and patients [15]. So, the fatigue of trying to understand speech and follow a conversation through face masks is compounded by the additional efforts of communication in a second or third language. This could translate into a perceived negative change in hearing ability.

The reported onset or worsening in tinnitus, in both the test and control groups, could also be due to stress and anxiety, whether associated with diagnosis of COVID-19 or as a result of the pandemic [16, 17], rather than a direct impact of the virus. It is also possible that the shift from working in a distracting office atmosphere to working from home in a quieter soundscape can increase awareness of the tinnitus.

Is COVID-19 associated with vestibular symptoms?

The present data suggest that patients who have been diagnosed with COVID-19 are more likely to self-report rotatory vertigo than those who have not had COVID-19. This finding survived control for age and whether the patients were hospitalized or not. Also, in contrast to the controls, self-reported vertigo attacks following COVID-19 diagnosis were described as experienced for the first time (i.e., onset), rather than as a worsening of pre-existing vestibular symptoms, by the majority (93.3%) of affected patients.

Dizziness symptoms such as light-headedness or instability were related to the severity of illness as estimated by the presence of respiratory and breathing difficulties, and were reported more by those who had severe symptoms that required hospitalisation, suggesting that these symptoms are not likely to be vestibular in origin.

Rotatory vertigo, however, which was reported by only 26.7% of the participants who experienced dizziness during the time they had COVID-19, was not related to the severity of their illness. These findings provide evidence that rotatory vertigo, which could be vestibular in origin, may be one of the many clinical manifestations of COVID-19, reported by 5% of the participants in the COVID-19 groups in the present study (4% in COVID-Hosp and 6% in COVID-Home).

Vestibular neuritis was reported in few studies as a neural manifestation of COVID-19. In a recently published case study [18], left superior vestibular neuritis was confirmed in a13-year-old girl with an objective peripheral assessment (Video Head Impulse Test) during a proven COVID-19 infection. Two other 2020 studies reported a case of vestibular neuritis in confirmed COVID-19 patients: the first [19] confirmed the diagnosis using tests of vestibular function; in the second [20], vestibular neuritis was reported as the final diagnosis without details about the peripheral vestibular evaluation.

However, the results of the present study should be interpreted with caution. The patients' descriptions of their symptoms, by using more specific words than *dizzy,* such as

vertigo, unsteadiness, light-headedness and *generalised weakness*, have been determined as critical in the establishment of the cause of dizziness [21]. In our study we are confident that we have examined rotatory vertigo. However, it is difficult to differentiate between vestibular disorders and other types of dizziness or to distinguish between peripheral and central vertigo without careful history taking and performing vestibular and neurological tests to confirm the diagnosis [21]. The majority of those who reported vertigo in the COVID-19 groups also reported other dizziness symptoms including unsteadiness or light-headedness. It is somewhat difficult for people to differentiate accurately between symptoms associated with dizziness, vertigo, and unsteadiness [22]. Therefore, it is possible that patients in our study might have been reporting other subjective dizziness symptoms as peripheral vertigo.

It is also possible that vertigo in some COVID-19 patients was not directly linked to the virus but rather triggered by the stress and anxiety [23] associated with the diagnosis of COVID-19, or as a result of developing benign paroxysmal positional vertigo caused by inactivity and long bed stays, especially in older patients and those who were severally ill with symptoms requiring hospitalisation [24, 25].

Future studies in which accurate history is obtained, along with all necessary diagnostic testing, are necessary to thoroughly investigate the leading cause and confirm the origin of the dizziness, whether peripheral (i.e., vestibular in origin) or secondary to any other possible central cause following COVID-19.

Limitations

Self-report measures may be unreliable, and lack sensitivity compared to laboratory-based measures. It is possible that lack of sensitivity affected the detection of recent changes in hearing abilities, resulting in an underestimate of the deterioration. Conversely, the reported changes in this present study, and those of other studies, may have been due to lack of sensitivity to pre-existing hearing loss, or a failure of patients to appreciate the influence of

environmental and psychological factors, which may have led to an overestimation of the deterioration.

The inadequacy of the hospital control group is a limitation. In particular, the health professional subgroup is not the best control for the anxiety of hospitalization, and communication difficulties, which may be experienced by patients. However, subgroup analysis showed similar patterns. Future studies should incorporate a more appropriate matching of controls. Also, the lack of consistent follow-up of our patients limits us from enquiring into the recovery time of the reported symptoms at the time of the interview, or even from determining the potential onset of new symptoms.

Conclusions

- The design of the current study avoids many of the limitations shared by the majority of the published studies on self-reported audio and/or vestibular symptoms associated with COVID-19, because it measured changes in audio-vestibular symptoms in confirmed severe and mild COVID-19 cases, relative to pre-COVID baselines, and compared the findings with controls.
- There were no significant differences between COVID-19 and control groups in the percentage of participants reporting deterioration in hearing and/or tinnitus.
- Patients who had been diagnosed with COVID-19 were more likely to self-report rotatory vertigo than those who had not had COVID-19.
- High quality comprehensive studies are needed, including lab-based clinical and subclinical measures, to investigate whether or not COVID-19 can cause audio-vestibular deficits.

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Disclosure statement

The authors declared no potential conflicts of interest.

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Table legends

Table 1. The percentages and number of cases of those who self-reported changes in any of the nine symptoms assessed in the questionnaire. For the two COVID-19 groups, these numbers give an estimation of the reported changes in symptoms between two difference values i.e., *during-to-before* COVID-19 and *after* (at the time of the interview)-*to-during* COVID-19. For the control groups, only percentages of the total number of cases who self-reported changes at the time of the interview compared to before the pandemic are provided. Changes in symptoms for the Control-Hosp sub-groups (i.e. Control-Hospitalised patients and Control-Healthcare professionals) are also reported. For hearing abilities, a composite score of the total number of participants who reported a change in any of the four assessed variables (i.e., sense of hearing, ease of conversing by telephone, ability to follow a conversation with background noise, or preferred volume while listening to various media) was calculated. See Table SM3 in supplementary materials for the reported changes in each of the four variables.

Table 2. *P*-values for comparisons between COVID-19 and control groups and sub-group in the four assessed categories and their related symptoms.

Figure legends

Figure 1. Distribution of common symptoms experienced by the COVID-19 participants *during* the acute phase (panel A) and the first noticed symptoms (panel B).

Figure 2. Percentages of participants who self-reported changes in smell or taste (panel A) and audio-vestibular symptoms (panel B) among the COVID-19 and control groups (and sub-groups). For the COVID-19 groups, these represent the percentages of those who reported deterioration in symptoms *during* or *after* the acute phase. For hearing abilities, a composite score of the total number of participants who reported a change in any of the four assessed variables was calculated. See Table SM3 in supplementary materials for the reported changes in each of the four variables.

List of Supplementary Materials

Table SM1. Demographic and health characteristics of the groups included in the analysis.

Table SM2. Symptoms reported by participants during the acute phase of COVID-19 and comparison between the two COVID-19 patient groups.

Table SM3. The percentages and number of cases of those who self-reported changes in any of the four hearing abilities variables.

Table SM4. The characteristics of those in the test and control groups and sub-groups who self-reported changes in audio-vestibular symptoms (hearing, tinnitus, and vertigo).

English version of the test group questionnaire.

Tables

Table 1. The percentages and number of cases of those who self-reported changes in any of the nine symptoms assessed in the questionnaire. For the two COVID-19 groups, these numbers give an estimation of the reported changes in symptoms between two difference values i.e., *during-to-before* COVID-19 and *after* (at the time of the interview)-*to-during* COVID-19. For the control groups, only percentages of the total number of cases who self-reported changes at the time of the interview compared to before the pandemic are provided. Changes in symptoms for the Control-Hosp sub-groups (i.e. Control-Hospitalised patients and Control-Healthcare professionals) are also reported. For hearing abilities, a composite score of the total number of participants who reported a change in any of the four assessed variables (i.e., sense of hearing, ease of conversing by telephone, ability to follow a conversation with background noise, or preferred volume while listening to various media) was calculated. See Table SM3 in supplementary materials for the reported changes in each of the four variables.

Categories and symptoms	Group (N)	Deterioration (during or after) n (%)	Resolved n (%)	Improving n (%)	Persisting n (%)	Deterioration further n (%)
Olfactory and gustatory abnormalities						
Smell	**COVID-Hosp (150)**	103 (68.7)	97 (64.7)	6 (4.0)	0 (0.0)	0 (0.0)
	Control-Hosp (117)	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	Sub-groups ***Control-Hospitalised patients (32)***	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	Control-Healthcare professionals (85)	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	COVID-Home (150)	91 (60.7)	86 (57.3)	4 (2.7)	1 (0.7)	0 (0.0)
	Control- Home (150)	0 (0.0)	N/A	N/A	0 (0.0)	N/A
Taste	**COVID-Hosp (150)**	67.3 (101)	95 (63.3)	6 (4.0)	0 (0.0)	0 (0.0)
	Control-Hosp (117)	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	Sub-groups ***Control-Hospitalised patients (32)***	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	Control-Healthcare professionals (85)	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	COVID-Home (150)	90 (60.0)	86 (57.3)	4 (2.7)	0 (0.0)	0 (0.0)
	Control-Home (150)	0 (0.0)	N/A	N/A	0 (0.0)	N/A
Auditory symptoms						
Hearing abilities *composite score % (n) of participants who reported any change in hearing abilities*	**COVID-Hosp (150)**	7 (4.7)	0 (0.0)	2 (1.3)	5 (3.3)	2 (1.3)
	Control-Hosp (117)	4 (3.4)	N/A	N/A	4 (3.4)	N/A
	Sub-groups ***Control-Hospitalised patients (32)***	1 (3.1)	N/A	N/A	1 (3.1)	N/A
	Control-Healthcare professionals (85)	3 (3.5)	N/A	N/A	3 (3.5)	N/A
	COVID-Home (150)	6 (4.0)	0 (0.0)	0 (0.0)	1 (3.1)	1 (3.1)
	Control-Home (150)	3 (2.0)	N/A	N/A	3 (2.0)	N/A
Tinnitus	**COVID-Hosp (150)**	8 (5.3)	2 (1.3)	1 (0.7)	5 (3.3)	0 (0.0)
	Control-Hosp (117)	5 (4.2)	N/A	N/A	5 (4.2)	N/A
	Sub-groups ***Control-Hospitalised patients (32)***	1 (3.1)	N/A	N/A	1 (3.1)	N/A
	Control-Healthcare professionals (85)	4 (4.7)	N/A	N/A	4 (4.7)	N/A
	COVID-Home (150)	7 (4.7)	4 (2.7)	0 (0.0)	1 (0.7)	0 (0.0)
	Control-Home (150)	6 (4.0)	N/A	N/A	4.0 (6)	N/A
Hyperacusis:	**COVID-Hosp (150)**	1 (0.7)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.7)
	Control-Hosp (117)	0 (0.0)	N/A	N/A	0 (0.0)	N/A

Stress, irritation or sensitivity as a cause of noise and certain sounds in the environment	***Sub-groups*** ***Control-Hospitalised patients (32)***	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	Control-Healthcare professionals (85)	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	COVID-Home (150)	2 (1.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Control-Home (150)	5 (3.3)	N/A	N/A	5 (3.3)	N/A
Dizziness						
Rotatory vertigo: The feeling that either you, or things around you, are spinning or moving	**COVID-Hosp (150)**	6 (4.0)	1 (0.7)	4 (2.7)	1 (0.7)	0 (0.0)
	Control-Hosp (117)	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	Sub-groups ***Control-Hospitalised patients (32)***	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	Control-Healthcare professionals (85)	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	COVID-Home (150)	9 (6.0)	2 (1.3)	7 (4.7)	0 (0.0)	0 (0.0)
	Control-Home (150)	3 (2.0)	N/A	N/A	2.0 (3)	N/A
Unsteadiness/ lightheaded (stability): Your confidence that you will not lose your balance or become unsteady when you walk around the house, up or down stairs, bend over and pick up something from the floor	**COVID-Hosp (150)**	34 (22.7)	18.0 (27)	7 (4.7)	0 (0.0)	0 (0.0)
	Control-Hosp (117)	1 (0.9)	N/A	N/A	1 (0.9)	N/A
	Sub-groups ***Control-Hospitalised patients (32)***	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	Control-Healthcare professionals (85)	1 (1.2)	N/A	N/A	1 (1.2)	N/A
	COVID-Home (150)	19 (12.7)	14 (9.3)	5 (3.3)	0 (0.0)	0 (0.0)
	Control-Home (150)	2 (1.3)	N/A	N/A	2 (1.3)	N/A
Ear symptoms						
Ear pressure	**COVID-Hosp (150)**	2 (1.3)	2 (1.3)	0 (0.0)	0 (0.0)	0 (0.0)
	Control-Hosp (117)	0 (0.0)	N/A	N/A	0 (0.0)	0 (0.0)
	Sub-groups ***Control-Hospitalised patients (32)***	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	Control-Healthcare professionals (85)	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	COVID-Home (150)	5 (3.3)	4 (2.7)	0 (0.0)	0 (0.0)	0 (0.0)
	Control- Home (150)	2 (1.3)	N/A	N/A	2 (1.3)	N/A
Otalgia: ear pain	**COVID-Hosp (150)**	1 (0.7)	1 (0.7)	0 (0.0)	0 (0.0)	0 (0.0)
	Control-Hosp (117)	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	Sub-groups ***Control-Hospitalised patients (32)***	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	Control-Healthcare professionals (85)	0 (0.0)	N/A	N/A	0 (0.0)	N/A
	COVID-Home (150)	1 (0.7)	1 (0.7)	0 (0.0)	0 (0.0)	0 (0.0)
	Control-Home (150)	1 (0.7)	N/A	N/A	1 (0.7)	N/A

Table 2. *P*-values for comparisons between COVID-19 and control groups and sub-group in the four assessed categories and their related symptoms.

Categories	**Symptoms**	**Comparison Between Groups (*p*-values)**			***Sub-group Analysis*** **Comparison between COVID-Hosp and Control-Hosp sub-groups (*p*-values)**	
		COVID-Hosp to Control-Hosp	**COVID-Home to Control-Home**	**COVID to Control**	**COVID-Hosp (150) to Control-Hospitalised patients (32)**	**COVID-Hosp (150) to control-Healthcare professionals (85)**
Olfactory and gustatory abnormalities	**Smell**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**
	Taste	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**
Auditory symptoms	**Hearing abilities**	0.761	0.501	0.362	0.677	0.374
	Tinnitus	0.779	>0.999	0.689	0.580	0.834
	Hyperacusis	>0.999	0.448	0.485	0.729	0.448
Dizziness	**Rotatory vertigo**	0.036*	0.038*	0.008*	0.05*	0.002**
	Unsteadiness/ lightheaded (stability)	<0.001**	<0.001**	<0.001**	0.003**	<0.001**
Ear symptoms	**Ear pressure**: pressure in the ear	0.505	0.448	0.182	0.512	0.282
	Otalgia: ear pain	>0.999	>0.999	>0.999	0.643	0.448

*Asterisks denote difference significant: *p < 0.05; **p significant following Holm-Bonferroni method of correction (**$P_k < \frac{0.05}{19+1-k}$).*

Figures

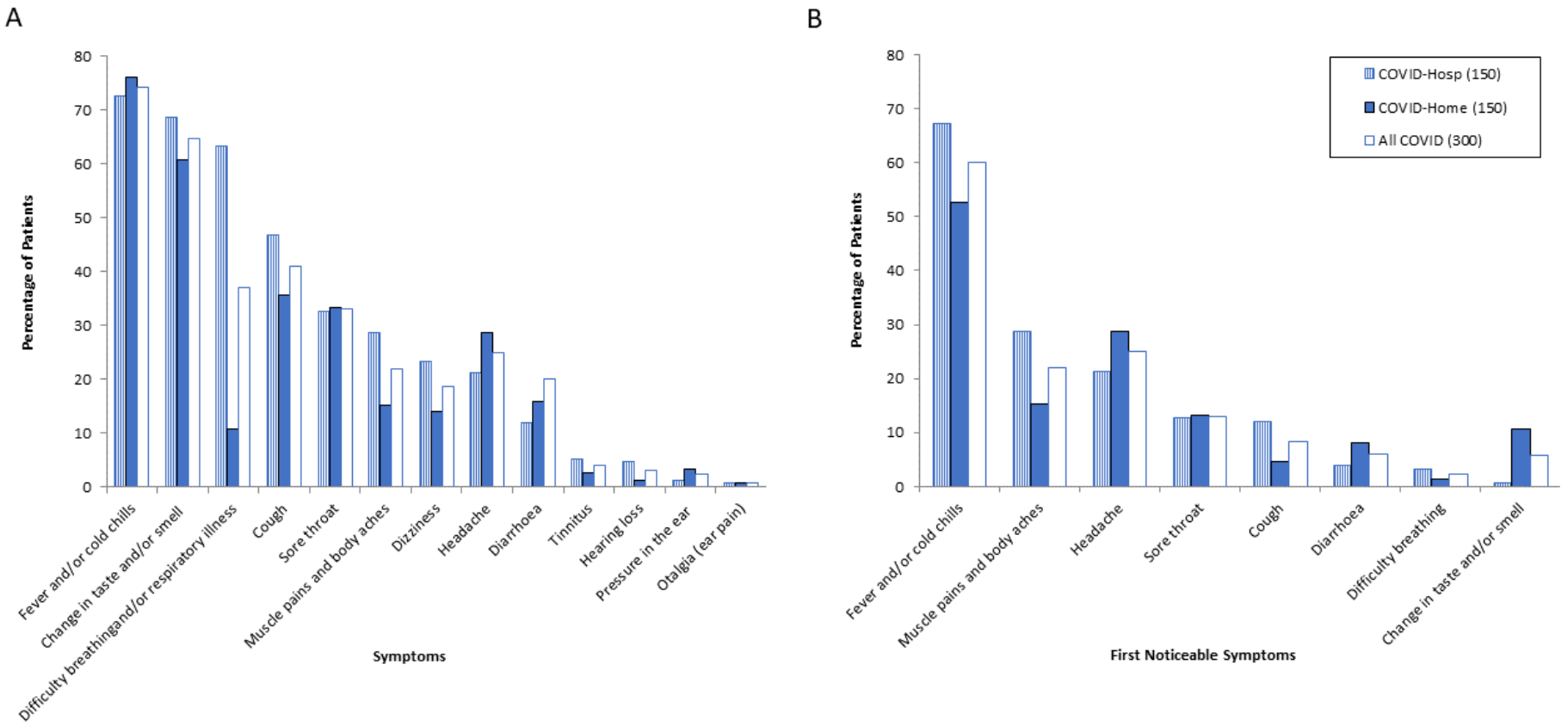

Figure 1. Distribution of common symptoms experienced by the COVID-19 participants *during* the acute phase (panel A) and the first noticed symptoms (panel B).

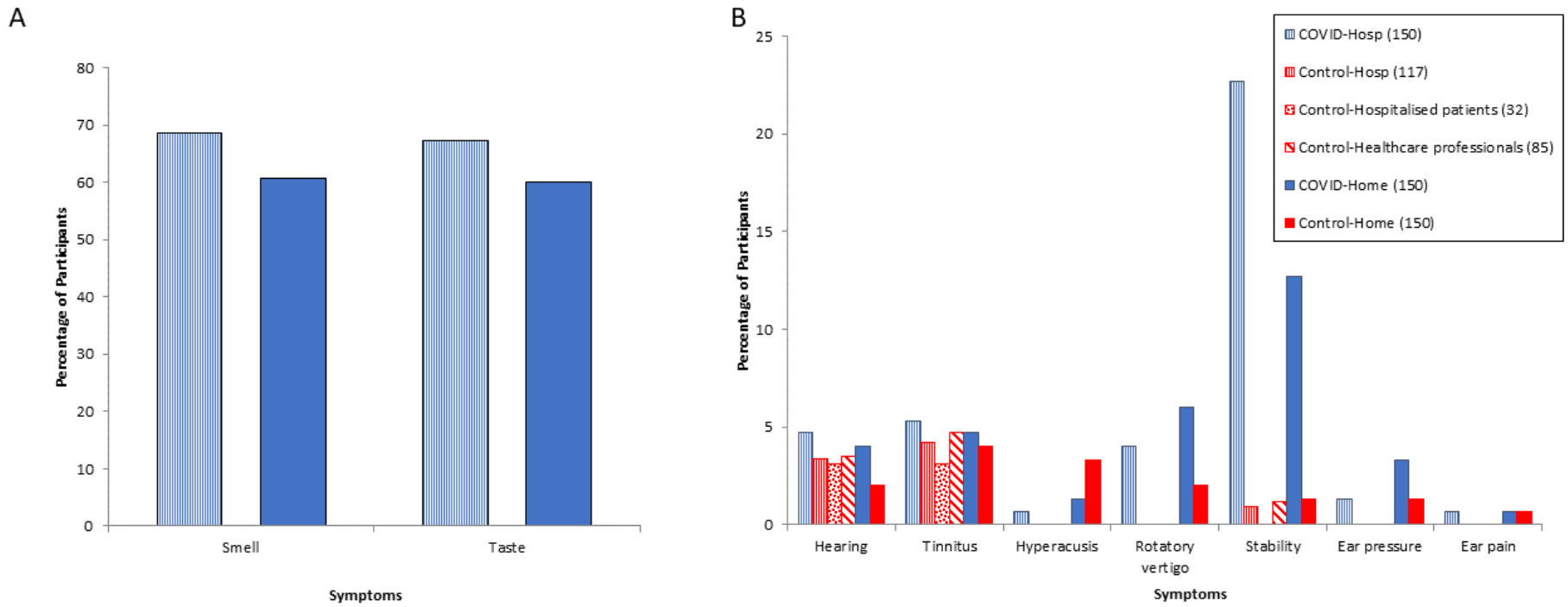

Figure 2. Percentages of participants who self-reported changes in smell or taste (panel A) and audio-vestibular symptoms (panel B) among the COVID-19 and control groups (and sub-groups). For the COVID-19 groups, these represent the percentages of those who reported

deterioration in symptoms *during* or *after* the acute phase. For hearing abilities, a composite score of the total number of participants who reported a change in any of the four assessed variables was calculated. See Table SM3 in supplementary materials for the reported changes in each of the four variables.