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Review of Audiological Findings in SARS-CoV-2 Infection

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Abstract

Since 2020 the world has been dealing with an acute respiratory syndrome pandemic caused by SARS-CoV-2. The main symptoms are fever, cough, and tiredness, accompanied by smell and taste loss. Due to neurotropism and infection mechanisms, SARS-CoV-2 can cause several neurological and sensory injuries. Its auditory impacts are controversial; however, cochlear hair cells and auditory pathways might be damaged. The aim of this review was identifying evidence underlying clinical association between COVID-19 and auditory implications which would help diagnosis and treatment response. Studies identified in databases Scielo (Scientific Electronic Library Online), Lilacs (Latin American Literature in Sciences Health), Pubmed (National Library of Medicine), Livivo and Scopus, published up to June 2021 for COVID-19 and auditory system impairments correlation and etiology were selected. Inclusion criteria were: Articles published in any language related to COVID-19 and audiological symptoms confirmed by audiological testing. Searching returned 1208 records and after applying eligibility criteria, 24 original research and 10 review articles were included. More frequent evaluations were pure tone audiometry, transient evoked otoacoustic emissions, tympanometry, and acoustic reflex test, sensorineural hearing loss being most prevalent. Recent studies support the relation between SARS-CoV-2 infection and audiological findings. Long term COVID-19 follow up should include systematic early audiological evaluation.

Summary: Recent findings support SARS-CoV-2 implications on cochlear hair cells and other auditory structures. Auditory dysfunctions are a possible consequence of COVID-19 since some symptoms such as sudden hearing loss, otitis, and tinnitus were reported. Vertical transmission of SARS-CoV-2 might contribute to congenital damages, impact on auditory abilities, and consequently, language acquisition. Raising potential impacts of SARS-CoV-2 infection on the auditory system based on recent case reports brings attention to mechanisms that underlie clinical association. Long term follow up of hearing function in suspected and confirmed cases of SARS-CoV-2 infection will support more effective clinical intervention.

Keywords: SAR-CoV-2 • COVID-19 • Coronavirus infection • Hearing loss • Hearing disorders • Auditory system

Introduction

In March 2020, the World Health Organization [1] announced the severe acute respiratory syndrome Coronavirus 2 (SARS-CoV-2) as a global pandemic. The novel Coronavirus typified in December 2019 uses a transmembrane enzyme called angiotensin-converting enzyme 2 (ACE2) for host cell entry [2-4]. The clinical manifestation for this infection was labelled Coronavirus disease 2019 (COVID-19). Various human cells express ACE2 [5-7] such as type 2 pneumocytes [8,9], cells of myocardium, gallbladder, liver and proximal kidney tubules [10], intestine and esophagus, leading to respiratory dysfunction and systemic infection development in severe cases [11]. The most common symptoms, fever, cough, and tiredness [12,13] are also accompanied by loss of smell and taste [14-16], and neurological manifestations [17-19] COVID-19 often progresses lethally to severe acute respiratory syndrome, acute cardiac injury, acute kidney injury, and septic shock [12,20].

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Several infections (e.g. Cytomegalovirus, rubella, measles, mumps, and meningitis) are responsible for about 30% of hearing loss in childhood [21], and are considered risk indicators [22]. SARS-CoV-2 impacts in the auditory system are still controversial. However, several researchers raised concerns of Coronavirus on cochlear hair cells and other auditory structures [23-26]. A vertical transmission of SARS-CoV-2 is also possible [27-30], and congenital damages could impact auditory skills [31] and consequently, language acquisition [32]. These concerns increase due to the presence of ACE2 receptors in the temporal lobe, which play a main role in language related tasks [7,33-35].

COVID-19 long term sequelae challenge rehabilitation services due to respiratory, neurological and neuromuscular damage, and long term hospitalizations [19,36-38]. Furthermore, some consequences might be caused by the clinical treatment, social isolation or by the direct action of SARS-CoV-2 on the Central Nervous System (CNS), such as worsening of communication and mental health issues [19,37,38]. Multiprofessional initiatives (e.g. speech therapy, physiotherapy and occupational therapy) should consider motor, respiratory, and functional rehabilitation procedures [39] to advance understanding about the long term impacts of COVID-19 pandemic.

This review aimed to raise potential impacts of SARS-CoV-2 infection on the auditory system. Therefore, identifying evidence that underlies clinical association between COVID-19 and auditory implication would support diagnostic and treatment approaches.

Materials and Methods

This article is a review of original studies published until June 2021, in the databases Scielo (Scientific Electronic Library Online), Lilacs (Latin American Literature in Sciences Health), Pubmed (National Library of Medicine), Livivo, and Scopus. The Boolean descriptors and operators were: Coronavirus infection OR COVID-19 and hearing OR hearing loss OR audiology OR cochlea OR auditory system. Inclusion criteria were articles published in any language, and related to COVID-19 and audiological symptoms confirmed by audiological testing or review articles. Exclusion criteria were articles with other COVID-19 sequelae, deafness accessibility and inclusion practices, or other audiovestibular symptoms.

Titles and abstracts contemplating the inclusion criteria were selected for full text reading (investigators NS, CE, PC) using the Rayyan tool for systematic review [40]. Full text review and data extraction were conducted by investigators NS, CE, PC and discussed with EM, HG, SB. Data extraction for analysis were the type of study, sample, audiological evaluation procedure, and outcomes.

Results

Database search returned 1208 records. Posterior duplicate removal left 583 records, of which 352 were excluded due to other COVID-19 sequela emphasis. Reading 231 titles and abstracts allowed 141 additional exclusion (58 described features on deafness accessibility and inclusion, 68 reported clinical recommendations and telehealth, and 15 described only other audiovestibular symptoms). 90 remaining records were assessed for eligibility, and 56 were excluded posterior to full text reading. 24 original research and 10 review articles on audiological symptoms associated with SARS-CoV-2 infection fulfilled the inclusion criteria (Figure 1) [41]. Table 1 summarizes auditory assessment and outcomes of recent original articles by type of study, sample size, gender, and age [42-64].

Table 1. Audiological symptoms associated with SARS-CoV-2 infection.

Identification	Type of study	Sample, gender, age	Audiological Assessment	Outcomes
Mustafa, Egypt May 2020, [25]	Cross-sectional Study	20, F/M, 20-50	PTA, tympanometry, TEOAE	Decreased high frequency PTA, TEOAE amplitudes significantly worse in the test group.
Fidan, Turkey May 2020, [42]	Case Report	1, F, 35	PTA, tympanometry	CHL PTA, type-b appearance in tympanometry in right ear.
Daikhes et al, Russia July 2020, [43]	Cross-sectional Study	78, M/F, 20-50	Tympanometry, TEOAE, Estapedial Acoustic Reflexes	Regular tympanometry and reflexes decreased TEOAE amplitude and signal-to-noise ratio.
Degen et al, Germany August 2020, [44]	Case Report	1, M, 60	TEOAE, MRI, "Audiologic Testing"	Complete deafness on the right side and profound SNHL on the left side. Signs of an inflammatory process in the cochlea
Kilic et al, Turkey August 2020, [45]	Case Series	5, M, 29-54	PTA, Tympanometry, Weber's test	20% of individuals with unilateral SNHL confirmed COVID-19 by RT-PCR.
Abdel Rhman and Abdel Wahid, Egypt September 2020, [46]	Case Report	1, M, 52	Rinne's test, Weber's test, PTA, Tympanometry, MRI	Bilateral positive Rinne test, Weber's test lateralized to the right side. Right normal hearing level and left severe SNHL with bilateral type A Tympanometry. Normal intracranial appearances.
Koumpa, Forde and Manjaly, United Kingdom October 2020, [47]	Case Report	1, M, 45	PTA, Rinne's test, Weber's test,	Left-sided SNHL with a negative Rinne's test ipsilateral and a Weber's test lateralized to the opposite side. Sudden onset SNHL.
Lang et al, Ireland October 2020, [48]	Case Report	1, F, 30	"Audiology testing", MRI	Profound high-frequency sudden SNHL in the right ear
Maharaj and Hari, South Africa October 2020, [49]	Case Report	1, M, 44	PTA, Tympanometry, Stapedial Acoustic Reflexes, Clinical vestibular testing, CT Scan, MRI	Normal thresholds for PTA and speech audiometry, falling tendency toward right side, caloric testing revealed an impaired function of the semicircular canals. CT Scan and MRI revealed congenital inner ear abnormalities.

Raad et al, Iran October 2020, [50]	Case Series	8, M/F, 20-45	PTA, self-report, otoscopy, CT Scan	Six cases of middle-ear effusion, three cases of typical acute otitis media, one case of tympanic membrane perforation. Most patients had CHL and mild SNHL at high frequencies.
Lamounier et al, Brazil November 2020, [51]	Case Report	1, F, 67	PTA, Tympanometry, Stapedial Acoustic Reflexes, MRI	Severe SNHL in the right ear, isolated hearing loss in the frequencies of 4 KHz and 8 kHz in the left ear, bilateral type A curve, and no bilateral contralateral stapedial acoustic reflexes.
Karimi-Galougahi et al, Iran December 2020, [52]	Case Series	6, M/F, 22-40	PTA	PTA revealed a sensorineural mechanism for the unilateral hearing loss
Aasfara et al, Morocco January 2021, [53]	Case Report	1, F, 36	PTA, Videonystagmography, MRI	Severe right SNHL, complete right vestibular areflexia on caloric examination with left-beating spontaneous horizontal and torsional nystagmus, normal MRI. Possible association between a variant of Guillain-Barré syndrome and vestibulocochlear neuritis and SARS-CoV-2 infection.
Chern et al, United States of America January 2021, [54]	Case Report	1, F, 18	PTA, Word Recognition Scores, Tympanometry, MRI	Moderate to severe SNHL in the right ear and moderate to profound SNHL in the left ear. Word recognition scores were 88% on the right and 80% on the left. Tympanometry was normal. Findings are consistent with bilateral intralabyrinthine hemorrhage.
Alves de Sousa et al., Portugal February 2021, [55]	Cross-sectional Study	60 (28 test group, 32 Control group) M/F, 56-60/47-65*	PTA PTA	Higher PTA thresholds (beginning at 1000 Hz) in COVID-19 patients with moderate-severe disease.
Gallus et al., Italy February 2021, [56]	Cross-sectional Study	48, M/F, 36-54**	PTA, Tympanometry, Acoustical Stapedial Reflexes, vHIT	PTA and vHIT gain within normality range
Savtale, India February 2021, [57]	Cross-sectional Study	185, M/F, 18-65	Weber's test	54.44% of patients reported hearing loss, Weber's test showed lateralization to the opposite side of the hearing loss.
Swain, Das e Lenka, India February 2021, [58]	Cross-sectional Study	16, M/F, 38-72	Tuning Fork PTA, Tympanometry, TEOAE, MRI Test,	2.45% patients were diagnosed with Sudden SNHL, of which 12.50% had bilateral sudden SNHL. 93.75% showed reduced amplitude of the TEOAE. In 10 patients (62.50%) with SNHL, MRI with contrast showed enhancement of the cochlea on the affected side.
Swain and Pani, February India 2021, [59]	Cross-sectional Study	28, M/F, 16-52	PTA, Tympanometry, TEOAE	5.93% were presented with hearing loss, 22 were presented with unilateral hearing loss and 6 were presented with bilateral hearing loss (3 mild conductive and 3 mild sensorineural). 60.71% SNHL presented with sudden onset. 66.67% of SNHL cases show high-frequency SNHL in PTA.
Chirakkal et al., Qatar April 2021, [60]	Case Report	1, F, 35	PTA, Weber's Test, Tympanometry, Stapedial Acoustic Reflexes, TEOEA	Low-frequency pure tone threshold, TEOAE and DPOAE low-frequency amplitudes were absent in the left side (suggesting outer hair cell damage), Weber's test lateralized for left side, bilateral Type-A tympanometry
Dharmarajan, India May 2021, [61]	Cross Sectional Study	100, M/F, 21–60	PTA, TEOAE	11% of the patients who had symptoms of hearing loss were confirmed by PTA and 48% of the patients who did not (42% SNHL, 6% CHL). 49% of patients referred to TEOAE in both ears; patients had conductive loss due to middle ear effusion.
Gerstacker et al, Germany May 2021, [62]	Case Report	1, M, 38	PTA, TEOAE, ABR, VNG, CT, MRI	Left acute deafness and right profound SNHL. No ABR potentials on left side, and V wave peak latency at 70 dB on the right side, normal inter peak latencies, VNG with under-excitability on the left side. Imaging presented no signs of a cochlear inflammatory process.

Mohan et al, USA May 2021, [63]	Case Report	1, M, 23	CT, portable PTA, tuning fork test	MHL in the right ear, opacification of the middle ear and mastoid.
Dror et al, Israel Jun 2021, [64]	Cross Sectional Study	16 (8 test group, 8 control group), M/F, 32-61, 29-60	PTA, Tympanometry, TEOEA, DPOEA, ABR	Normal PTA Thresholds and type-A tympanometry for asymptomatic COVID-19 recovered patients and matched controls, no differences in TEOAE and DPOAE between groups, ABR waveforms normal as compared with standard.
Abbreviations: F: Female; M: Male; PTA: Pure Tone Audiometry; TEOAE: Transient Evoked Otoacoustic Emissions; DPOAE: Distortion Product Otoacoustic Emissions; ABR: Auditory Brainstem Response; MRI: Magnetic Resonance Imaging; CT: Computed Tomography; vHIT: Video-Head Impulse Test; VNG: Videonystagmography; SNHL: Sensorineural Hearing Loss; CHL: Conductive Hearing Loss, MHL: Mixed Hearing Loss. *Age range was estimated based on the mean age and standard-deviation described in the original publication (test group: 63 ± 6:80; control group: 56:03 ± 9:28). **Age range was estimated based on the mean age and standard-deviation described in the original publication (45 ± 9.6)				

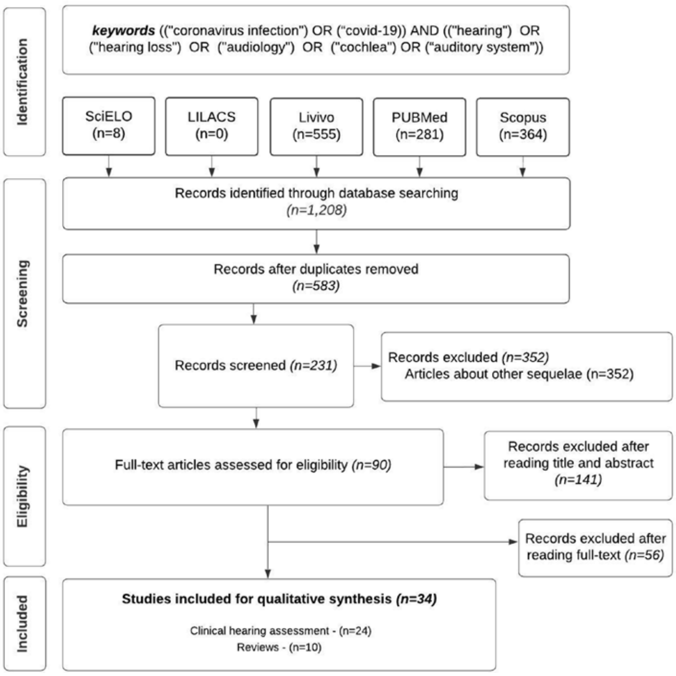

Figure 1. This figure presents the flow diagram of the steps for article selection.

Original studies

Recent COVID-19 associated audiological findings were presented in 24 original studies with 12 (50.0%) published in 2020 and 12 (50.0%) by June 2021. Researches from 16 countries highlighted evidences in 4 articles from India (16.66%), 2 from Egypt, Germany, United States of America and Turkey (8.33% each), and one from each country: Brazil, Ireland, Israel, Italy, Morocco, Portugal, Qatar, Russia, South Africa and United Kingdom (4.16% each). The research design was case reports (12 cases, 50%), cross-sectional studies (9 studies, 37.5%) and case series (3 series, 12.5%). Cross-sectional study samples ranged from 16 to 185 participants, and age variation from 16 to 72 years.

Audiological evaluations were pure tone audiometry for audiological diagnosis (20 of 24 articles, 83.34%), reported using accumetric testing, TEOAE and MRIand (2 articles, 8.33%), and two articles were unspecified (8.33%). 18 articles that used pure tone audiometry also used otoacoustic emissions, tympanometry and acoustic reflexes testing as a complementary hearing assessment, and only two considered tonal hearing thresholds. Audiological outcomes were primarily presented as data thresholds (19 of 24 articles, 79.17%), and no audiological outcomes (5 articles, 20.83%). 9 of 20 studies that used PTA presented the occurrence of Sensorineural Hearing Loss (45.0%), 1 with Conductive Hearing Loss (5.0%), 3 with both SNHL and CHL (15.0%), 1 with Mixed Hearing Loss (5.0%), 3 with Normal Hearing Thresholds (15.0%), and 3 (15.0%) presented no information. 13 studies highlighted laterality of hearing loss, with 3 bilateral (23.08%), 8 unilateral (61.53%) and 2 (15.39%) describing both possibilities of impairment. Four studies which used PTA (20.0%) reported a sudden onset of hearing loss while the other 16 (80.0%) presented no appearance of symptoms. 13 studies reported complementary assessments alteration in TEOAE exams (4 articles, 38.46%), accumetric assessments (4 articles, 30.77%), tympanometry (2 articles, 15.39%), World Recognition Scores (1 article, 7.69%), and Auditory Brainstem Responses (1 article, 7.69%).

Review articles

10 review articles were recently published. 5 presented a systematic review [65-69], one presented an integrative review [70], and four presented a literature review [71-74].

Almufarrij, Uus and Munro [65] published in 2020 a rapid systematic review, updated in 2021 [66], analyzing prospective, retrospective, cohort, cross sectional, case reports and case control studies about Coronavirus effects in the audiovestibular system. They considered any audiovestibular disorder, such as hearing changes, tinnitus and vertigo, estimating prevalence of 7.6% for hearing loss, 14.8% for tinnitus and 7.2% for rotatory vertigo among COVID-19 patients. However, based on evaluation of the quality of scientific evidence, they suggest that those values might be overestimated, once there is a lack of high quality studies, such as case control studies, within the literature. Jafari, Kolb and Mohajerani [69] performed a meta-analysis to determine the event rate of the same symptoms and found statistically significant values of 3.1% of hearing loss, 4.5% of tinnitus and 12.2% of dizziness caused by SARS-CoV-2. Authors implied that the heterogeneity among studies, insufficient evidence and small sample size contributed to these findings. They performed reliability and validity evaluations through a tool used specifically to appraise different studies designs (quality rates between 50% and 72.5%).

In a systematic review on otologic manifestations of SARS-CoV-2, Maharaj et al. [67] also highlighted the small sample size of the publications. Authors selected studies ranked through a tool for risk of bias assessment in studies of interventions, leading to 7 studies (narratively described) with a total of 28 patients. They suggest the need for studies with larger samples.

Despite the small sample size criticism, a potential effect of the Coronavirus on the appearance or worsening of audiovestibular symptoms is still under investigation. Soylemez and Ertugrul [68] on a systematic review of audiovestibular symptoms pointed to sensorineural hearing loss as the main condition, followed by tinnitus and dizziness. Similarly, Narozny, Tretiakow and Skorek [73] concluded that there is a possible causality between COVID-19 and Hearing Loss (which might be manifested as a first symptom of SARS-CoV-2 infection), but not with vertigo/dizziness. However, Andalib et al. [71] discussed PNS manifestations (such as SNHL) associated with COVID-19, and considered that auditory complications are rare manifestations in COVID-19 with a possible incidental association without causal relationship. Saniasiaya [74] reviewed the SNHL relation to COVID-19, and reasoned the need for early detection of hearing loss to guarantee early treatment and strengthening of scientific evidence based on objective clinical evaluation. Likewise, Beckers et al [72] suggested PCR tests in patients with auditory symptoms considering the appearance of SNHL during SARS-CoV-2 infection progression.

Discussion

Audiological findings

Since the onset of COVID-19 pandemic several case reports pointed out possible effects on the auditory system. In April 2020, a sensorineural hearing loss patient was infected with SARS-CoV-2 in Thailand [75], and underwent only respiratory care. No change in her hearing loss was documented. Few days later, Fidan [42] reported a case of unilateral audiological findings, such as conductive hearing loss, tinnitus, and otalgia (with bulging tympanic membrane and hyperemia pointed by otoscopy, and type-B tympanometry) associated with respiratory symptoms, and reverse transcription polymerase chain reaction (RT-PCR) positive for SARS-CoV-2. At time, the authors implied that, in the absence of a complete understanding of the multiple actions of the SARS-CoV-2 in the human organism, given the tropism for several systems that contain the ACE2 receptor for the SARS like virus [76], it is necessary a complete evaluation of each patient in search of symptoms that differ from standard symptoms of COVID-19 [13,42]. Raad et al. [50] have described similar findings, reporting middle ear effusion, typical acute otitis media, and even tympanic membrane perforation, leading to conductive and sensorineural hearing loss. In 2021, Dharmarajan et al. [61] and Mohan et al. [63] also described findings of conductive or mixed hearing loss due to middle ear commitment which may suggest that respiratory infection caused by COVID-19 can spread to the middle ear and thus reach the sensory components of the auditory pathway.

Lamounier et al. [51] reported a case of a 67 years old female with confirmed COVID-19 and sudden hearing loss complaints. It was performed audiological assessment by audiometry, tympanometry and stapedial acoustic reflexes, presenting severe sensorineural hearing loss in the right ear, isolated hearing loss in the frequencies of 4 KHz and 8 KHz in the left ear, bilateral type-A curve, and no bilateral contralateral stapedial acoustic reflexes. Those results were compared to previous evaluations, inferring a worsening of this condition. The patient showed an improvement after drug treatment (oral and intratympanic corticosteroid therapy). Other authors, performing similar assessments with Pure Tone Audiometry (PTA) have described similar findings of sensorineural mechanisms for hearing loss in patients with confirmed SARS-CoV-2 infection [44,47,51,52]. Regarding the onset of symptoms, other studies described a predominance of sudden perception of hearing loss [47,59].

Cure and Cumhur Cure [76] pointed out that damage to hearing function due to SARS-CoV-2 infection may be related to the neurosensory impairment of the auditory cortical center in the temporal lobe of the brain, where ACE2 can be found. Scientific findings from several researchers indicate that this area has moderate expression of ACE2, making it susceptible to direct viral infection, causing damage to target cells, and triggering injuries in the pointed region [2,7,33-35]. Another possible mechanism may also be related to hearing cells hypoxia, an idea that is based on the proven involvement in cases of Severe Acute Respiratory Syndrome [77,78], as well as due to circulatory disorders [79], thus generating sensorineural loss and tinnitus, mainly caused by oxidative stress [77]. Degen et al. [44] performed Transient Evoked Otoacoustic Emissions (TEOAE) and brain Magnetic Resonance Imaging (MRI), and associated those tests results with signs of inflammatory process in the cochlea, while Chern et al [54] pointed out to an intralabyrinthine hemorrhage, and Swain, Das and Lenka [58] pointed to cochlea alteration on MRI results. On the other hand, Gerstacker et al. [62] showed no relation between cochlear inflammation and confirmed SNHL in data of CT and MRI.

Mustafa [25], in a case control COVID-19 study of asymptomatic patients aged between 20 and 50 years, reported a relevant auditory clinical finding. High frequency pure tone thresholds (4 kHz, 6 kHz, and 8 kHz) and TEOAE amplitude values were worse for the test group. These findings support that SARS-CoV-2 may cause deleterious effects in cochlear cells and primarily Outer Hair Cells (OHC), despite no sensitivity abnormality described [25,43,55,58]. There are two possible hypothesis proposed:

- Local hypoxia leading to loss of OHC [79,80]
- Direct virus action effects on possible target cells that express ACE2 in the intracochlear environment facilitating viral adsorption in the target cell [25,81]. Both proposals require additional studies for confirmation. These deleterious effects may be unnoticed, as somes papers described no hearing sensitivity abnormalities in asymptomatic to COVID-19 patients. Other studies confirmed OHC damage by TEOAE amplitude observation [58,60,61] with perception of hearing loss.

A type of Murine Coronavirus strain (called JHM strain, or JHMV) is related to Sub-Acute Demyelinating Encephalomyelitis in rats [82], similar to multiple sclerosis, leading to demyelinating lesions in the brainstem, pons, thalamus, cerebellum or spinal cord, and in neuronal cell culture [83]. This aspect is present in SARS-CoV-2 [83,84] indicating an evolutionary characteristic maintenance since other predecessor Coronaviruses [85,86]. Multiple sclerosis presents 1%-3% of sudden hearing loss cases [86,87] and also injuries involving the 8th cranial nerve and cochlear nucleus [88,89]. Such demyelinating effects may increase the possibility of auditory system impairment in other human Coronaviruses which have similar mechanism to the SARS-CoV-2 [90], as recent evidences show the sudden onset of hearing loss associated with SARS-CoV-2 infection [47,54,58,59], and a possible association between Guillain-Barre syndrome (a peripheral demyelinating condition) and vestibular neuritis with hearing loss manifestation [53].

Ogier et al. [26] infer that SARS-CoV-2 can affect the auditory pathway, and the Auditory Brainstem Responses (ABR) could assess its brainstem related disorders. Considering a possible correlation between other human Coronaviruses and multiple Sclerosis, this condition may cause desynchronization and alter the morphology of waves III and V of ABR, and result in auditory processing disorders [91]. Furthermore, a Brazilian-Canadian report cites other human Coronaviruses with neurotropism associated with the development of neurodegenerative diseases such as Parkinson's disease and multiple sclerosis [92,93]. It pointed out that neurodegenerative processes can last for decades and can be triggered or accelerated by inflammatory response to the virus. Systemic inflammatory mediators can access the CNS and trigger damage by impairing the blood brain barrier function [94]. ABR application to complementary diagnosis of hearing loss in COVID-19 patients has shown contradictory results. Gerstacker et al. [62] described a delay on absolute V wave peak in a case report of confirmed bilateral SNHL, while Dror et al [64] described regular ABR waveforms to asymptomatic and recovered COVID-19 patients.

The included studies presented different methods for hearing assessment. The most used exams were PTA, tympanometry and TEOAE, however, some studies used accumetric tests, such as the Rinne and Weber tests [46,57]. In order to search for the origin of hearing loss, the use of imaging tests such as MRI and Computed tomography (CT) Scan was also mentioned. One study used the video Head Impulse Test (vHIT), and showed no significant difference among COVID-19 patients and control group [56]. Maharaj and Hari [49], Gallus et al. [56] and Dror et al. [64] described normal PTA thresholds in symptomatic and asymptomatic COVID-19 patients. Systematic investigations are necessary to confirm whether the evaluative methods suggested in the literature are in fact efficient to understand audiological findings related to COVID-19.

Medication

Regarding drug treatments, substances derived from quinine, like chloroquine and hydroxychloroquine are known to have a transient hearing loss, tinnitus, and dizziness [95]. Fernandes et al [96] reported the case of a 51 years old female who presented otologic complaints (bilateral hearing loss and tinnitus) after 3 years of regular use of hydroxychloroquine. A similar case was reported by Khalili et al [97], who described a 57 years old male with bilateral progressive hearing loss after three months of hydroxychloroquine administration. In this case, self-report and audiogram thresholds improved after discontinued medication. WHO does not recommend hydroxychloroquine to prevent or treat COVID-19 [98]. Thus, medication may act as a confounding variable in audiological findings related to COVID-19.

Other manifestations

Most human Coronaviruses have documented neurotropic and neuroinvasive potential with distinct entry pathways (hematogenous, transcribidal, retrograde neuronal) [99,100]. Entry pathway mechanisms and progression of known conditions (such as Severe Acute Respiratory Syndrome (SARS), Middle East Respiratory Syndrome (MERS), sepsis, Intensive Care Unit (ICU), and mechanical ventilation) supported identifying the main complications that COVID-19 can lead to, and other manifestations. It includes polyneuropathy, critical illness myopathy, cardiological and neurological sequelae (as dizziness, paresthesia, smell, and taste disturbance) [101]. Smell and Tastes disorders prevalence have been documented at a rate that goes from 15% [102] to 85.6% or 88% of infections for SARS-CoV-2 [103]. However, the UK Health Security Agency [104] showed a minor prevalence of 13% in the recent omicron variant. Anosmia and ageusia were reported as early symptoms in cases of COVID-19 mild to asymptomatic. Ageusia can be related to central and peripheral nervous system damage, as in cranial nerves. Lesions on the chorda tympani, which are present in the middle ear, may lead to taste disorders [105]. Regarding anosmia, it does not appear to be associated with inflammation in the nasal mucosa, rhinorrhea, or constipation, but with the entry of the virus into the olfactory pathway [103,106].

Retrospective COVID-19 neurological manifestations demonstrated 36.4% of manifestations of the CNS, 24.8% of the peripheral nervous system, and 10.7% of musculoskeletal injuries. Among the neurological disorders, acute cerebrovascular disease, conscious disturbance, and skeletal muscle injury stand out. Mao et al [19] highlighted the role of comorbidities in the risk of contamination and worsening of the disease, describing high rates of hypertension, diabetes, obesity, and the elderly among the most severe cases of the disease. Inflammation caused by the virus can contribute to neuroinflammatory processes and increase the risk of neurological syndromes.

Thus, SARS-CoV-2 impact on the CNS may lead to acute neurological changes, worsen neurological conditions under development and increase the chance of injury or the severity of damage caused by other disorders [107] and also may lead to long covid symptoms [108]. These considerations imply that rehabilitation services need adaptations to receive new demands caused by the pandemic. The possibility of auditory impairment caused by SARS-Cov-2 infection must be taken into account by professionals working in health and rehabilitation services to COVID-19. Social, psychological, and emotional impacts may be related to hearing loss, such as impairments in language comprehension, which can damage personal relationships [109].

Although there are few reports about the vertical transmission of SARS-CoV-2 [30], there is a chance of hearing impairments presence in infected babies, considering the consequences of other congenital viral infections, like Cytomegalovirus and rubella virus [110,111]. Cognitive, reading, and learning disabilities, also speech and language delays may occur in children with congenital or early hearing loss [112]. It is stated that early diagnosis and intervention can improve the development of language, communication, and hearing abilities [113]. Thus, in the routine of maternal and child health services, newborn hearing screening should be part of the neonatal assessment flows of children with congenital SARS-CoV-2 infection and those with an inaccurate diagnosis.

Studies have unveiled the occurrence of behavior problems related to language delay, and decreased skills of social and emotional development. It can even generate learning difficulties and worsen adaptation to the scholarly context, which can persist to adolescence and adult age if no hearing aids and speech therapy were initiated [114]. Adults with acquired hearing loss or age related impairments, like presbycusis, might experience difficulty to understand high pitched consonant sounds, difficulty to separate speech sounds from environmental sounds, struggle against tinnitus and other handicaps, bringing impacts on quality of life and communication [115,116]. Lin et al [117] point out that various functionalities may be damaged by hearing impairments, such as driving, walking, and occurrence of falls, beyond the correlation with dementia, social and cognitive decline among the elderly.

Health professionals can also collaborate with communicational accessibility. Considering that several patients may have hearing loss, even if temporary (due to otitis or use of ototoxic drugs, for example), some measures inherent to social distance can be reformulated. The distance and the use of opaque masks and face shields can impair lip reading and interpretation of facial expressions. Also, this personal protective equipment attenuates the intensity of the spoken voice.

Conclusion

Several reports have pointed out that SARS-CoV-2 infection may lead to damage to hearing function by cortical and peripheral mechanisms, due to viral infection of temporal lobe, local hypoxia or oxidative stress process in the cochlea, drug ototoxicity or even demyelinating lesions in the brainstem and auditory pathway. Considering the possibility of audiological impairments related to COVID-19, such as conductive and sensorineural hearing loss, tinnitus, otitis and otalgia, a follow up of the hearing function in suspected or confirmed cases of SARS-CoV-2 infection must be tracked. Health services should consider early audiological assessment associated with COVID-19, including anamnesis of hearing loss, ear pain, tinnitus, dizziness, and otoscopy, mainly in the presence of upper airway and nasopharynx involvement. Further large scale investigations in hearing and central auditory processing is needed to support objective auditory assessment related to COVID-19.

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Conflicts of Interest

The authors declare no conflict of interest.

References

1. WHO/Europe Coronavirus Disease (COVID-19) Outbreak-WHO Announces COVID-19 Outbreak a Pandemic.

2. Li, W, Moore MJ, Vasllieva N and Sui J, et al. “Angiotensin-Converting Enzyme 2 is a Functional Receptor for the SARS Coronavirus.” *Nature*

426(2003):450–454.

3. Hoffmann, M, Kleine WH, Kruger N and Muller M, et al. “The Novel Coronavirus 2019 (2019-nCoV) uses the SARS-Coronavirus Receptor ACE2 and the Cellular Protease TMPRSS2 for Entry into Target Cells.” *bioRxiv* 31(2020):929042.

4. Letko, M, Marzi A and Munster V. “Functional Assessment of Cell Entry and Receptor Usage for SARS-CoV-2 and Other Lineage B Betacoronaviruses. Nat Microbiol 5(2020):562–569.

5. Sungnak, W, Huang N, Becavin C and Berg M. “SARS-CoV-2 Entry Factors are Highly Expressed in Nasal Epithelial Cells Together with Innate Immune Genes.” *Nat Med* 26(2020):681–687.

6. Barker, H and Parkkila S. “Bioinformatic Characterization of Angiotensin-Converting Enzyme 2, the Entry Receptor for SARS-CoV-2.” *bioRxiv* 13(2020):038752.

7. Harmer, D, Gilbert M, Borman R and Clark KL. “Quantitative mRNA Expression Profiling of ACE 2, a Novel Homologue of Angiotensin Converting Enzyme.” *FEBS Lett* 532(2002):107–110.

8. Hamming, I, Timens W, Bulthuis MLC and Lely AT, et al. “Tissue Distribution of ACE2 Protein, the Functional Receptor for SARS Coronavirus: A First Step in Understanding SARS Pathogenesis.” *J Pathol* 203(2004):631–637.

9. Wan, Y, Shang J, Graham R and Baric RS, et al. “Receptor Recognition by the Novel Coronavirus from Wuhan: An Analysis Based on Decade-Long Structural Studies of SARS Coronavirus.” *J Virol* 94(2020):e00127-20.

10. Chai, X, Hu L and Zhang Y. “Specific ACE2 Expression in Cholangiocytes may Cause Liver Damage after 2019-nCoV Infection.” *bioRxiv* 3(2020):e931766.

11. Li, YC, Bai WZ and Hashikawa T. “The Neuroinvasive Potential of SARS-CoV2 may be at least Partially Responsible for the Respiratory Failure of COVID-19 Patients.” *J Med Virol* 92(2020):6552-555.

12. Chen, N, Zhou M, Dong X and Qu J, et al. “Epidemiological and Clinical Characteristics of 99 Cases of 2019 Novel Coronavirus Pneumonia in Wuhan, China: A Descriptive Study.” *Lancet* 395(2020):507–513.

13. Guan, W, Ni Z, Hu Y and Liang W, et al. “Clinical Characteristics of 2019 Novel Coronavirus Infection in China.” *medRxiv* 6(2020):e20020974.

14. Klopfenstein, T, Zahra H, Kadiane O and Lepiller NJ, et al. “New Loss of Smell and Taste: Uncommon Symptoms in COVID-19 Patients on Nord Franche-Comte Cluster, France.” *Int J Infect Dis* 100(2020):117-122.

15. Giacomelli, A, Pezzati L, Conti F and Bernacchia D, et al. “Self-Reported Olfactory and Taste Disorders in Patients With Severe Acute Respiratory Coronavirus 2 Infection: A Cross-sectional Study.” *Clin Infect Dis* 71(2020):889–890.

16. Menni, C, Sudre CH, Steves CJ and Ourselin S, et al. “Quantifying Additional COVID-19 Symptoms will Save Lives.” *Lancet* 20(2020):31281-31282.

17. Tsai, LK, Hsieh ST and Chang YC. “Neurological Manifestations in Severe Acute Respiratory Syndrome.” *Acta Neurol Taiwan* 14(2005):113–119.

18. Cai, JH, Wang XS, Ge YL and Xia AM, et al. “First Case of 2019 Novel Coronavirus Infection in Children in Shanghai.” *Chinese J Pediatr* 58(2020):E002.

19. Mao, L, Jin H, Wang M and Hu Y, et al. “Neurologic Manifestations of Hospitalized Patients with Coronavirus Disease 2019 in Wuhan, China.” *JAMA Neurol* 77(2020):683–690.

20. Huang, C, Wang Y, Li X and Ren L, et al. “Clinical Features of Patients Infected with 2019 Novel Coronavirus in Wuhan, China.” *Lancet* 395(2020):497–506.

21. Krug, E, Cieza A, Chadha S and Sminkey L, et al. “Childhood Hearing Loss Strategies for Prevention and Care.” *ISBN* 4(2016):1510325.

22. Huang, C. “Joint Committee on Infant Hearing [JCIH]. 2019 Position Statement: Principles and Guidelines for Early Hearing Detection and Intervention Programs.” *J Early Interv* 120(2019):898-921.

23. Pitkaranta, A, Virolainen A, Jero J and Arruda E, et al. “Detection of Rhinovirus, Respiratory Syncytial Virus, and Coronavirus Infections in Acute Otitis Media by Reverse Transcriptase Polymerase Chain Reaction.” *Pediatrics* 102(1998):291–295.

24. Buzatto, GP, Tamashiro E, Proenca M and Saturno TH, et al. “The Pathogens Profile in Children with Otitis Media with Effusion and Adenoid Hypertrophy.” *PLoS One* 12(2017):1–12.

25. Mustafa, MWM. “Audiological Profile of Asymptomatic COVID-19 PCR-Positive Cases.” *Am J Otolaryngol* 41(2020):102483.

26. Ogier, M, Andeol G, Sagui E and Bo GD. “How to Detect and Track Chronic Neurologic Sequelae of COVID-19? Use of Auditory Brainstem Responses and Neuroimaging for Long-Term Patient Follow-up.” *Brain Behav Immun Heal* 5(2020):100081.

27. Vivanti, AJ, Vauloup-Fellous C, Prevot S and Zupan V, et al. “Transplacental Transmission of SARS-COV-2 Infection.” *Nat Commun* 11(2020):1–7.

28. Kirtsman, M, Diambomba Y, Poutanen SM and Malinowski AK, et al. “Probable Congenital Sars-COV-2 Infection in a Neonate Born to a Woman with Active SARS-COV-2 Infection.” *CMAJ* 192(2020):E647–E650.

29. Dong, L, Tian J, He S and Zhu C, et al. “Possible Vertical Transmission of SARS-CoV-2 from an Infected Mother to Her Newborn.” *JAMA* 10(2020):4621.

30. Kotlyar, A, Grechukhina O, Chen A and Popkhadze S, et al. “Vertical Transmission of COVID-19: A Systematic Review and Meta-analysis.” *Am J Obstet Gynecol* 7(2020):49.

31. Moore, DR. “Auditory Processing Disorders: Acquisition and Treatment.” *J Commun Disord* 40(2007):295–304.

32. Yoshinaga, IC, Sedey AL, Coulter DK and Mehl AL. “Language of Early and Later-Identified Children with Hearing Loss.” *Pediatrics* 102(1998):1161–1171.

33. Donoghue, M, Hsieh F, Baronas E and Godbout K, et al. “A Novel Angiotensin-Converting Enzyme-Related Carboxypeptidase (ACE2) Converts Angiotensin I to Angiotensin 1-9.” *Circ Res* 9(2000):87.

34. Tipnis, SR, Hooper NM, Hyde R and Karran E, et al. “A Human Homolog of Angiotensin-Converting Enzyme: Cloning and Functional Expression as a Captopril-Insensitive Carboxypeptidase.” *J Biol Chem* 275(2000):33238–33243.

35. Cookson, BT and Brennan MA. “Pro-Inflammatory Programmed Cell Death.” *Trends Microbiol* 9(2001):113-114.

36. Wu, Y, Xu X, Chen Z and Duan J, et al. “Nervous System Involvement after Infection with COVID-19 and Other Coronaviruses.” *Brain Behav Immun* 3(2020):31.

37. Kiekens, C, Boldrini P, Andreoli A and Avesani R, et al. “Rehabilitation and Respiratory Management in the Acute and Early Post-Acute Phase. Instant Paper from the field on Rehabilitation Answers to the COVID-19 Emergency.” *Eur J PhysRehabil Med* 56(2020):323–326.

38. Rogers, JP, Chesney E, Oliver D and Pollak TA, et al. “Psychiatric and

Neuropsychiatric Presentations Associated with Severe Coronavirus Infections: A Systematic Review and Meta-Analysis with Comparison to the COVID-19 Pandemic." *The Lancet Psychiatry* 7(2020):611–627.

39. Lew, HL, Oh Park and Cifu DX. "The War on COVID-19 Pandemic: Role of Rehabilitation Professionals and Hospitals." *Am J Phys Med Rehabil* 99(2020):571–572.

40. Ouzzani, M, Hammady H, Fedorowicz Z and Elmagarmid A. "Rayyan-A Web and Mobile App for Systematic Reviews." *Syst Rev* 5(2016):384-394.

41. Moher, D, Liberati A, Tedlaff J and Altman DG. "Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement." *PLoS Med* 6(2009):e1000097.

42. Fidan, V. "New Type of Corona Virus Induced Acute Otitis Media in Adult." *Am J Otolaryngol* 10(2020):102487.

43. Daikhes, NA, Karneeva OV, Machalov AS and Kuznetcov AO, et al. "Audiologicheskii Profile Patsientov Pri Zabolevanii, Vyzvannom Virusom SARS-CoV-2." *Vestn Otorinolaringol* 85(2020):6–11.

44. Degen, C, Lenarz T and Willenborg K. "Acute Profound Sensorineural Hearing Loss After COVID-19 Pneumonia." *Mayo Clin Proc* 95(2020):1801–1803.

45. Kilic, O, Kalcioglu MT, Cag Y and Tuysuz O, et al. "Could Sudden Sensorineural Hearing Loss be the Sole Manifestation of COVID-19? An Investigation into SARS-COV-2 in the Etiology of Sudden Sensorineural Hearing Loss." *Int J Infect Dis* 97(2020):208-211.

46. Abdel, R and Abdel WA. "COVID-19 and Sudden Sensorineural Hearing Loss, A Case Report." *Otolaryngol Case Rep* 16(2020):100198.

47. Koumpa, FS, Forde CT and Manjaly JG. "Sudden Irreversible Hearing Loss Post COVID-19." *BMJ Case Rep* 13(2020):238-419.

48. Lang, B, Hinde J and Conlon B. "Coronavirus Disease 2019 and Sudden Sensorineural Hearing Loss." *J Laryngol Otol* 10(2020):1–3.

49. Maharaj, S and Hari K. "Congenital Inner Ear Abnormalities and COVID-19-Related Ear Infections." *Ear Nose Throat J* 101(2020):NP308-NP310.

50. Raad, N, Ghorbani J, Mikaniki N and Haseli S, et al. "Otitis media in Coronavirus Disease 2019: A Case Series." *J Laryngol Otol* 135(2020):10–13.

51. Lamounier, P, Franco Goncalves V, Ramos HVL and Gobbo DA, et al. "A 67-Year-Old Woman with Sudden Hearing Loss Associated with SARS-CoV-2 Infection." *Am J Case Rep* 21(2020):e927519.

52. Karimi, GM, Naeini AS, Raad N and Mikaniki N, et al. "Vertigo and Hearing Loss during the COVID-19 Pandemic-Is there an Association?" *Acta Otorhinolaryngol Ital* 40(2020):463–465.

53. Aasfara, J, Hajjij A, Bensouda H and Ouhabi H, et al. "A Unique Association of Bifacial Weakness, Paresthesia and Vestibulocochlear Neuritis as Post-COVID-19 Manifestation in Pregnant Women: A Case Report." *Pan Afr Med J* 38(2021):30.

54. Chern, A, Famuyide AO, Moonis G and Lalwani AK. "Bilateral Sudden Sensorineural Hearing Loss and Intralabyrinthine Hemorrhage in a Patient with COVID-19." *Otol Neurotol* 42(2021):e10–e14.

55. Alves, de Sousa F, Costa RP, Xara S and Pinto AN, et al. "SARS-CoV-2 and Hearing: An Audiometric Analysis of COVID-19 Hospitalized Patients." *J Otol* 16(2021):158-164.

56. Gallus, R, Melis A, Rizzo D and Piras A, et al. "Audiovestibular Symptoms and Sequelae in COVID-19 Patients." *J Vestib Res* 31(2021):381-387.

57. Savtale, S, Hippargekar P, Bhise S and Kothule S. "Prevalence of Otorhinolaryngological Symptoms in Covid 19 Patients." *Indian J Otolaryngol head neck Surg* 5(2021):1–7.

58. Swain, SK, Das S and Lenka S. "Sudden Sensorineural Hearing Loss among COVID-19 Patients-Our Experiences at an Indian Teaching Hospital." *Siriraj Med J* 73(2021):77–83.

59. Swain, SK and Pani SR. "Incidence of Hearing Loss in COVID-19 Patients: A Covid Hospital-Based Study in the Eastern Part of India." *Int J Curr Res Rev* 13(2021):103–107.

60. Chirakkal, P, Al Hail AN, Zada N and Vijaya Kumar DS. "COVID-19 and Tinnitus." *Ear Nose Throat J* 100(2021):160S–162S.

61. Dharmarajan, S, Bharathi MB, Sivapuram K and Prakash BG, et al. "Hearing Loss-a Camouflaged Manifestation of COVID 19 Infection." *Indian J Otolaryngol Head Neck Surg* 73(2021):494–498.

62. Gerstacker, K, Speck I, Riemann S and Aschendorff A, et al. "Deafness after COVID-19?" *HNO* 69(2021):92–95.

63. Mohan, S, Workman A, Barshak M and Welling DB, et al. "Considerations in Management of Acute Otitis Media in the COVID-19 Era." *Ann Otol Rhinol Laryngol* 130(2021):520-527.

64. Dror, AA, Kassis-Karayanni N, Oved A and Daoud A, et al. "Auditory Performance in Recovered SARS-COV-2 Patients." *Otol Neurotol* 42(2021):666-670.

65. Almufarrij, I, Uus K and Munro KJ. "Does Coronavirus Affect the Audio-Vestibular System? A Rapid Systematic Review." *Int J Audiol* 59(2020):487-491.

66. Almufarrij, I and Munro KJ. "One Year on: An Updated Systematic Review of SARS-CoV-2, COVID-19 and Audio-Vestibular Symptoms." *Int J Audiol* 60(2021):935-945.

67. Maharaj, S, Bello Alvarez M, Mungul S and Hari K. "Otologic Dysfunction in Patients with COVID-19: A Review." *Laryngoscope Investig Otolaryngol* 5(2020):1192-1196.

68. Soylemez, E and Ertugrul S. "COVID-19 and Audio-Vestibular System: A Systematic Review." *Selcuk Saglık Dergisi* 1(2020):33-40.

69. Jafari, Z, Kolb BE and Mohajerani MH. "Hearing Loss, Tinnitus, and Dizziness in COVID-19: A Systematic Review and Meta-Analysis." *Can J Neurol Sci* 49(2021):184-195.

70. Ribeiro, GE and Silva DPC. "Audiological Implications of COVID-19: An Integrative Literature Review." *Rev CEFAC* 23(2021):e9620.

71. Andalib, S, Biller J, Di Napoli M and Moghimi N, et al. "A. Peripheral Nervous System Manifestations Associated with COVID-19." *Curr Neurol Neurosci Rep* 21(2021):9.

72. Beckers, E, Chouvel P, Cassetto V and Mustin V. "Sudden Sensorineural Hearing Loss in COVID-19: A Case Report and Literature Review." *Clin Case Rep* 9(2021):2300-2304.

73. Narozny, W, Tretiakow D and Skorek A. "Can the SARS-CoV-2 Virus Damage Human Hearing and Balance?" *Med Pr* 72(2021):321-325.

74. Saniasiaya, J. "Hearing Loss in SARS-CoV-2: What Do We Know?" *Ear Nose Throat J* 100(2021): 152S–154S.

75. Sriwijitalai, W and Wiwanitkit V. "Hearing Loss and COVID-19: A Note." *Am J Otolaryngol* 41(2020):102473.

76. Ge, XY, Li JL, Yang X and Lou CA, et al. "Isolation and Characterization of a bat SARS-like Coronavirus that uses the ACE2 Receptor." *Nature* 503(2013):535–538.

77. Cure, E and Cumhur CM. "Comment on Hearing loss and COVID-19: A note." *Am J Otolaryngol* 41(2020):102513.

78. Herridge, MS, Tansey CM, Matte A and Tomlinson G, et al. "Functional

Disability 5 Years after Acute Respiratory Distress Syndrome." *N Engl J Med* 364(2011):1293–1304.

79. Li, H, Liu L, Zhang D and Xu J, et al. "SARS-CoV-2 and Viral Sepsis: Observations and Hypotheses." *Lancet* 395(2020):10235, 1517-1520.

80. Rebillard, G and Lavigne RM. "Effect of Reversible Hypoxia on the Compared Time Courses of Endocochlear Potential and $2f1-f2$ Distortion Products." *Hear Res* 62(1992):142-148.

81. Prieve, BA and Fidgerald TS. "Otoacoustic Emissions. In Handbook of Clinical Audiology, 7th ed., Kad, J. Lippincott Williams and Wilkins: Philadelphia, USA." *Clin Aud* 7(2014):357-379.

82. Wege, H, Watanabe R and Meulen V. "Relapsing Subacute Demyelinating Encephalomyelitis in Rats during the Course of Coronavirus JHM Infection." *J Neuroimmunol* 6(1984):325–336.

83. Pasick, JM and Dales S. "Infection by Coronavirus JHM of Rat Neurons and Oligodendrocyte-Type-2 Astrocyte Lineage Cells during Distinct Developmental Stages." *J Virol* 65(1991):5013–5028.

84. Domingues, R, Mendes CMC, Leite FBV and Sabino EC, et al. "First Case of SAR-Coronavirus-2 Sequencing in the Cerebrospinal Fluid of a Patient with Suspected CNS Demyelinating Disease." *Preprint* 10(2020):31801.

85. Zanin, L, Saraceno G, Panciani PP and Renisi G, et al. "SARS-CoV-2 can Induce Brain and Spine Demyelinating Lesions." *Acta Neurochirurgica* 162(2020):1491-1494.

86. Hung, ECW, Chim SSC, Chan PKS and Tong YK, et al. "Detection of SARS Coronavirus RNA in the Cerebrospinal Fluid of a Patient with Severe Acute Respiratory Syndrome." *Clin Chem* 49(2003):2108–2109.

87. Fischer, C, Mauguiere F, Ibanez V and Confavreux C, et al. "The Acute Deafness of Definite Multiple Sclerosis: BAEP Patterns." *Electroencephalogr Clin Neurophysiol* 61(1985):7-15.

88. Furman, JM, Durrant JD and Hirsch WL. "Eighth Nerve Signs in a Case of Multiple Sclerosis." *Am J Otolaryngol* 10(1989):376-381.

89. Bergamaschi, R, Romani A, Zappoli F and Versino M, et al. "MRI and Brainstem Auditory Evoked Potential Evidence of Eighth Cranial Nerve Involvement in Multiple Sclerosis." *Neurology* 48(1997):270-272.

90. Desforges, M, Coupanec A, Dubeau P and Bourgouin A, et al. "Human Coronaviruses and Other Respiratory Viruses: Underestimated Opportunistic Pathogens of the Central Nervous System?" *Viruses* 12(2019):14.

91. Furst, M and Levine RA. "Hearing Disorders in Multiple Sclerosis. In The Human Auditory System, Handbook of Clinical Neurology." *Clin Neu* 129(2015):649–665.

92. Fazzini, E, Fleming J and Fahn S. "Cerebrospinal Fluid Antibodies to Coronavirus in Patients with Parkinson's Disease." *Mov Disord* 7(1992):153-158.

93. Murray, RS, Brown B, Brian D and Cabirac GF. "Detection of Coronavirus RNA and Antigen in Multiple Sclerosis Brain." *Ann Neurol* 31(1992):525-533.

94. Platt, MP, Bolding KA, Wayne CR and Chaudhry S, et al. "Th17 Lymphocytes Drive Vascular and Neuronal Deficits in a Mouse Model of Postinfectious Autoimmune Encephalitis." *Proc Natl Acad Sci* 117(2020):6708–6716.

95. Eby, TL, Arteaga AA and Spankovich C. "Otologic and Audiologic Considerations for COVID-19." *Otolaryngol Neck Surg* 163(2020):110–111.

96. Fernandes, MR, Soares DBR, Thien CI and Carneiro S. "Hydroxychloroquine Ototoxicity in a Patient with Systemic Lupus Erythematosus." *An Bras Dermatol* 93(2018):469–470.

97. Who, 2020. Who Discontinues Hydroxychloroquine and Lopinavir/Ritonavir Treatment Arms for Covid-19.

98. Khalili, H, Dastan F and Dehghan MSA. "A Case Report of Hearing Loss Post use of Hydroxychloroquine in a HIV-Infected Patient." *Daru* 22(2014):20.

99. Baig, AM, Khaleeq A, Ali U and Syeda H. "Evidence of the COVID-19 Virus Targeting the CNS: Tissue Distribution, Host-Virus Interaction, and Proposed Neurotropic Mechanisms." *ACS Chem Neurosci* 11(2020):995–998.

100. Carod, AJ. "Complicaciones Neurologicas Por Coronavirus Y COVID-19." *Rev Neurol* 70(2020):311-322.

101. Sheehy, LM. "Considerations for Postacute Rehabilitation for Survivors of COVID-19." *JMIR Public Heal Surveill* 6(2020):e19462.

102. Lee, Y, Min P, Lee S and Kim SW. "Prevalence and Duration of Acute Loss of Smell or Taste in COVID-19 Patients." *J Korean Med Sci* 35(2020):e174.

103. Lechien, JR, Chiesa ECM, Siati DR and Horoi M, et al. "Olfactory and Gustatory Dysfunctions as a Clinical Presentation of Mild-to-Moderate forms of the Coronavirus Disease (COVID-19): A Multicenter European Study." *Eur Arch oto rhino-laryngology* 277(2020):2251-2261.

104. UK Health Security Agency. SARS-Cov-2 Variants of Concern and Variants Under Investigation in England. Technical Briefing 34.

105. Obiefuna, S and Donohoe C. "Neuroanatomy, Nucleus Gustatory. Treasure Island: StatPearls Publishing, 7 (2020).

106. Vaira, LA, Salzano G, Deiana G and De Riu G. "Anosmia and Ageusia: Common Findings in COVID-19 Patients." *Laryngoscope* 130(2020):1787.

107. De Felice, FG, Tovar MF, Moll J and Munoz D, et al. "Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) and the Central Nervous System." *Trends Neurosci* 43(2020):355-357.

108. Spudich, S and Nath A. "Nervous System Consequences of COVID-19." *Science* 375(2022):267-269.

109. Ribas, A, Kozlowski L, Almeida G and Marques JM, et al. "Qualidade de vida: Comparando Resultados em Idosos Com E Sem Presbiacusia." *Rev Bras Geriatr Gerontol* 17(2014):353-362.

110. Wild, NJ, Sheppard S, Smithells RW and Holzel H, et al. "Onset and Severity of Hearing Loss due to Congenital Rubella Infection." *Arch Dis Child* 64(1989):1280-1283.

111. Fowler, KB, Dable AJ, Boppana SB and Pass RF. "Newborn Hearing Screening: Will Children with Hearing Loss Caused by Congenital Cytomegalovirus Infection be Missed?" *J Pediatr* 135(1999):60–64.

112. Fidpatrick, E. "Neurocognitive Development in Congenitally Deaf Children." *Handb Clin Neurol* 129(2015):335-356.

113. Pattisapu, P, Evans SS, Noble AR and Norton SJ, et al. "Defining Essential Services for Deaf and Hard of Hearing Children during the COVID-19 Pandemic." *Otolaryngol Neck Surg* 163(2020):91-93.

114. Netten, AP, Rieffe C, Theunissen SCPM and Soede W, et al. "Early Identification: Language Skills and Social Functioning in Deaf and Hard of Hearing Preschool Children." *Int J Pediatr Otorhinolaryngol* 79(2015):2221-2226.

115. Blustein, J, Wallhagen M, Weinstein B and Chodosh J. "Time to Take Hearing Loss Seriously." *Jt Comm J Qual Patient Saf* 46(2019):3-8.

116. Smith, AK, Ritchie CS, Miao Y and Boscardin WJ, et al. "Self-Reported

Hearing in the Last 2 Years of Life in Older Adults." *J Am Geriatr Soc* 64(2016):1486-1491.

117. Lin, FR, Thorpe R, Gordon SS and Ferrucci L. "Hearing Loss Prevalence and Risk Factors among Older Adults in the United States." *J Gerontol A Biol Sci Med Sci* 66(2011):582–590.

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