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COVID-19: Preliminary recommendations from the SFORL

Telemedicine in Audiology. Best practice recommendations from the French Society of Audiology (SFA) and the French Society of Otorhinolaryngology-Head and Neck Surgery (SFORL)

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ABSTRACT

Objectives: Access to diagnosis and treatments for auditory disorders and related pathologies has regressed in France during the COVID-19 pandemic, posing a risk to the patient's chance of recovery. This best practice recommendations guide aims to list the existing technological solutions for the remote examination of a patient with hearing complaint, and to outline their benefits and, where applicable, their limitations.
Methods: The recommendations were developed both from the clinical experience of the medical experts who drafted the guide, and from an extensive review of the literature dealing with clinical practice recommendations for tele-audiology. Tele-audiometry solutions were identified on the basis of a search engine query carried out in April 2020, prior to verification of their availability on the European market.
Results: Video otoscopy solutions allow for the teletransmission of images compatible with a high-quality diagnosis, either by connecting via internet to a tele-health platform or using a smartphone or a tablet with an iOS or Android operating system. Using the same telecommunication methods, it is possible to remotely conduct a pure-tone audiometry test in accordance with standard practice, a speech-in-quiet or a speech-in-noise audiometry test, as well as objective measures of hearing. Clinical and paraclinical examinations can be accessed by the physician to be interpreted on a deferred basis (asynchronous tele-audiology). Examinations can also be conducted in real time in a patient, at any age of life, as long as a caregiver can be present during the installation of the transducers or the acoumetry. Tele-audiology solutions also find application in the remote training of future healthcare professionals involved in the management of deafness and hearing impairment.

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Conclusion: Under French law, tele-otoscopy is a medical procedure that is either a tele-expertise (asynchronous adive) or a teleconsultation act (synchronous advice). Subjective and objective evaluation of the patient's hearing functions can be done remotely provided that the listed precautions are respected.

1. Introduction

One of the significant consequences of the COVID-19 pandemic is the increased number of medical teleconsultations and the greater consideration given to their development. In tele-audiology, as in all specialities, digital healthcare aims to use technological innovations to perform medical procedures and organise treatment. Until recently, the practice of medical audiology could be pursued only in the codified framework of a face-to-face meeting between the patient and their practitioner in adapted premises with technical facilities enabling the conduct of clinical ENT examinations and of audiovestibular testing in accordance with standard practice. Tele-medicine calls the principles of traditional medical practice into question, namely i) unity of place, the patient and practitioner not being present together in the same place, ii) unity of time, the patient and practitioner being able to work synchronously or not and iii) unity of action, the patient and practitioner being even more encouraged to work in a coordinated way. In this context, tele-audiology can be conceived as having three distinct levels of granularity depending on what is prioritised: self-screening for sensory disability and its consequences, help from a caregiver or medical/paramedical staff managing the patient in their everyday life, or the opinion of the expert consulted to interact remotely with the patient. This practice recommendations guide drawn up by a group of medical experts from the French Society of Audiology and the French Society of Otorhinolaryngology Head and Neck Surgery will address the current conditions for remotely performing and interpreting (directly i.e. then and there, or deferred) clinical otoscopic examinations and subjective and objective measures of hearing (including the necessary equipment), the remote training of healthcare professionals, as well as the characteristics specific to children and elderly subjects.

2. Best practice recommendations

2.1. Tele-examination in audiology

2.1.1. The practice of otoscopy in telehealth

2.1.1.1. Literature review. The use of tele-otoscopy is not a recent practice; it was described at the end of the 70s. However, the development of high-speed internet has enabled its more widespread use. Tele-otoscopy involves capturing an image or a short video recording that will be sent to the remote physician. In most publications, this image is captured by a "facilitator", who is not an expert in otoscopy, but a health worker with a variable level of training depending on the health service. This image is then assessed by the remote physician either directly (synchronous procedure) or later on (asynchronous procedure).

Most of the studies used an asynchronous assessment for a mass screening of otologic pathologies in regions where access to treatment is difficult. In studies, assessing the asynchronous analysis of image capture, the authors conclude that there is a good correlation between remote and face-to-face examinations, but with a high rate of poor quality or uninterpretable images. Aronzon et al. [1] found a sensitivity of 90 and 91%, respectively, with the video and the microscopic examination, but a better specificity with the face-to-face examination (93% versus 79%). Patricoski et al. [2] used video otoscopy to monitor transtympanic ventilation tubes. The correlation between remote and face-to-face otoscopy was high (79–85%, $\kappa = 0.67–0.76$). However, 18% of the images were of insufficient quality for diagnosis. Kokesh et al. [3] come to the same conclusion with a concordance of 76–80% ($\kappa = 0.64–0.71$), with 21% of the images being of poor quality. This poor image quality is linked to different factors such as the presence of earwax, a particular orientation of the ear canal, but also technical aspects such as poor focus or an image capture that doesn't include all of the tympanic area. To resolve these technical issues, the use of short videos was evaluated. The rate of poor quality images falls to 14% for Smith et al. [4] and 13% for Biagio et al. [5], while maintaining a good concordance when the remote evaluator was an ENT specialist ($\kappa = 0.70–0.74$) or a general practitioner ($\kappa = 0.68–0.75$). All of the studies agree that prior training on the basics of otoscopy and on the removal of earwax blockage improves the quality of the tele-otoscopy procedure [6,7].

2.1.1.2. Application in the specific context of French healthcare system. From a regulatory point of view, the otoscopy procedure is a medical procedure (Fig. 1). Its conduct cannot be delegated to another healthcare professional. This regulatory constraint makes it impossible to rely on a facilitator, as is done in other countries, and de facto compromises any tele-otoscopy procedure carried out on French soil. As for clearing out excess of earwax, this can only be performed by a physician or by a nurse through medical prescription (article. R.4311-7 of the Public Health Code and decree 2004-802 dated 29/07/2004). In the practice of telemedicine, there is a separation between the technical service (performed by the facilitator) and the intellectual service of interpreting the examination (conducted by the remote physician). The absence of dissociation between the technical and intellectual services in the medical technical procedures defined by the French National Authority for Health is a massive obstacle to the development of telemedicine procedures in otology. Whereas nurses and care assistants are authorised to take tympanic temperature, the same procedure conducted to capture an image or a video is not authorised by law.

In keeping with the law, the facilitator must be a physician (generalist or specialist) and the remote opinion requested will be a specialist or subspecialist one. As part of amendment 6 to the Medical Convention dated 14 June 2018 defining telemedicine procedures, if the opinion is given during an instance of video communication with the patient, this is a teleconsultation. The physician consulted may have received documents beforehand, including otoscopic images. The medical convention provided for the possibility of a joint consultation: the patient in the presence of one physician and at the same time in teleconsultation with a second physician. If the opinion is given by a requested physician to a requesting physician via secure message exchanges, without a video link with the patient, this is an instance of tele-expertise. Regarding equipment, besides what is required to establish a secure two-way connection necessary for a teleconsultation, the remotely-used otoscope needs only have features allowing it to record images in a standard electronic format (jpeg, tif, mpeg, avi, etc.), or video in a format greater than 640×480 pixels and a recording of at least 25 frames per second.

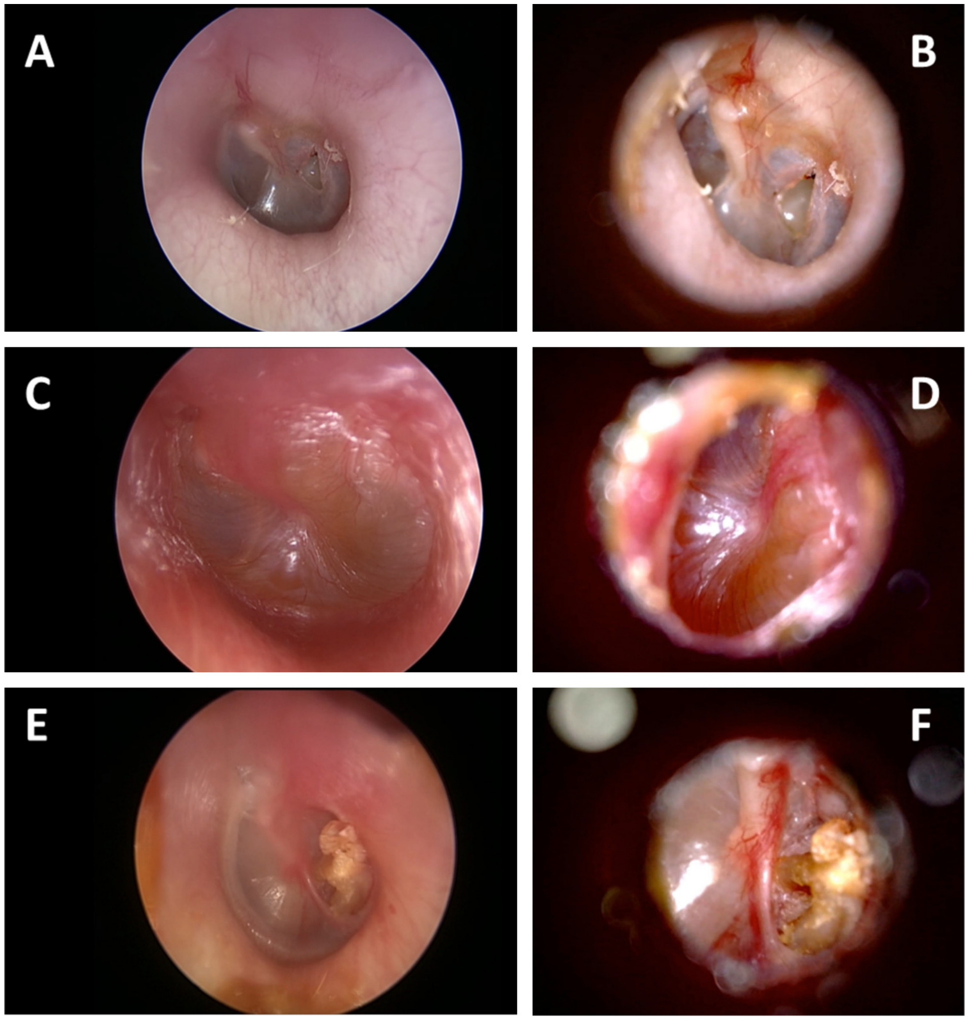

Fig. 1. Examples of video-otoscopy (A, C and E) and smartphone otoscopy (B, D and F). Real-time video-otoscopy was performed using a 4-mm, 0° endoscope (Hopkins Optic) and a high-definition video recorder for different pathologies: perforated eardrum (A), serous otitis media (C), and cholesteatoma (E). Images of the same eardrums were acquired using a digital otoscope connected to a smartphone (perforated eardrum (B), serous otitis media (D) and cholesteatoma (F)). These can be easily transmitted wirelessly to a computer or to any equipment connected to the Internet via Wifi or 3/4G network for remote interpretation.

2.1.2. Audiometry in telemedicine: levels of service, tests that can be conducted, and equipment required

The following tele-audiometry solutions were identified on the basis of a search engine query carried out in April 2020, when the most recent system could be offered to users in the context of the COVID-19 pandemic. They are all available on the European market. For the most part, their technological development had been closely monitored in recent years by the French Society of Audiology, in direct contact with their designers.

2.1.2.1. Self-administered screening tests. There are apps available in French, on smartphones and tablets using an iOS or Android operating system, which comply with the French National Authority for Health's framework on the best practices for healthcare apps and connected devices. After verifying a sufficiently low level of background noise, they enable a self-administered air conduction test with a pair of off-the-shelf headphones (Table 1). One of these apps enables the patient to perform a speech-in-noise audiometry test using an adaptive procedure. It is validated by increments of 2 dB and does not call on mental substitution as it uses series of digits triplets [8]. Its special feature is to enable the detection of asymmetrical or conductive hearing impairments thanks to an antiphasic presentation between the two ears which invokes the principle of binaural unmasking. According to this physiological principle, when speech signals are supplied binaurally in noise but in phase inversion, there is usually an improvement in the signal-to-noise ratio at which the speech signal is correctly recognized 50% of the time. As this improvement is absent in cases of unilateral or conductive hearing loss, it is thus possible to detect them [9]. Where the subject is identified as not having normal hearing for their age, these self-administered tests have a screening purpose leading to the recommendation of a medical consultation.

2.1.2.2. Tele-audiometry for an assisted patient. In this configuration, the patient can agree to a healthcare structure where a caregiver assists not only with installation (verifying the quality of the sound environment, launching the tele-audiometry software installed on a connected electronic device, preparing the air and bone conduction tests), but also to ensure that responses to auditory stimulations are correctly given (Fig. 2). If necessary, the caregiver can enter this information in place of the patient. In a synchronous tele-audiology mode, the practitioner connects via the web to the tele-audiology platform to which the caregiver will give access. The practitioner then controls the audiometry software remotely to conduct the examination. In an asynchronous tele-audiology mode, it is the patient alone or the caregiver who performs the test, the practitioner accessing the hearing test results on a deferred basis to interpret them.

Table 1
Tele-audiometry solutions for screening purposes.

Solution	Product overview	Types of hearing tests	Types of hearing impairments targeted	AC	BC	Masking	Pure-tone audiogram	Speech audiometry
Höra	Android & iOS app	Speech-in-noise	Symmetrical hearing impairment; asymmetrical, unilateral, and conductive hearing impairments thanks to an antiphasic presentation between the two ears	Air conduction (headphones)	Not available	Not available	Not available	Speech material Interaural antiphasic digit presentation (ten lists of 27 digit triplets, uttered by a female speaker) Noise Stationary noise with the long-term average spectrum of the test digits material, delivered binaurally and synchronously Parameter measured = SRT50 (Speech Reception Threshold 50) Signal-to-noise ratio at which the speech signal is correctly recognized 50% of the time Adaptive procedure The triplet is considered as correctly perceived if all the numbers are. The speech-to-noise ratio (SNR) varies in fixed steps (4 dB for the first three triplets, then 2 dB) from an initial SNR level of 0 dB (one-up one-down procedure) until the SRT50 is obtained. The SRT50 is calculated as the average of the last 19 iterations. Standards SRT50 = -18.4 dB
Mimi hearing test	Android & iOS app (more effective on iOS)	Pure-tone audiogram	Symmetrical hearing impairment; asymmetrical and unilateral impairments with each ear tested separately	Air conduction (iOS EarPods, Air pod, Aventhon Sennheiser HDA 200 and 300)	Not available	Yes	Automated audiometry (keep button pressed while heard, release when no longer heard)	Not available

Fig. 2. Principle of digital audiometry with air and bone conduction stimulation (headphones, earphones, free field). Any connected computer can be use as an audiometer, the transducers being connected to a USB port, for example. Resources are thus centralised: multilingual word lists, test protocols and results, questionnaires, creation of audiological databases.

2.1.2.3. Interaction between the practitioner and the patient without a third party. From the practice, the practitioner remotely accesses the patient's electronic device, on which the tele-audiometry software is installed, in order to start it. Thanks to this remote control, all of the audiometric tests gathered on the patient's electronic device can be administered. Their results are immediately analysed as part of a teleconsultation. In this synchronous tele-audiology mode, the practitioner can see multiple patients from one place as long as they have access to the tele-audiometry solution that the practitioner has chosen. Table 2 outlines the various existing tele-audiometry solutions, assisted or not, specifying the audiometric procedure used for each one, the types of hearing impairment detected, the tests that can be carried out (pure-tone, supraliminal pure-tone, speech-in-quiet and/or speech-in-noise, dichotic), as well as advanced features. An effective audiometry system should meet the following criteria, at a minimum. First, it has to provide high-quality visual contact to allow the tester to verify that the transducers are correctly positioned, and the patient or caregiver to correctly understand the instructions. It also has to be able to measure, even monitor the patient's background noise level. The tester must carry out a pure-tone audiogram in accordance with standard practice as per the modified Hughson–Westlake procedure (Down 10 – Up 5), with systematic contralateral masking for bone conduction and also for air conduction as soon as there is transcranial transmission loss above 50 dB. He has to provide validated lists of words in the relevant language for speech-in-silence and speech-in-noise audiometry tests (with an adaptive procedure for the most recent speech-in-noise audiometry tests). Finally, this system must have calibrated and easily replaceable transducers (headset, intra-auricular inserts, bone vibrators).

Traditionally, carrying out a pure-tone audiometry requires monitoring the sound environment to determine the 0 dB HL threshold for all the normal frequencies tested. Typically, to meet these requirements, the audiometry is conducted in a soundproof booth adapted to these standards [10]. Unless the installation of audiometric booths is being considered throughout the country, tele-audiometry must adapt to not having a booth. Several methods can be used to overcome this condition. It is possible to not test the threshold between 0 and 25 dB HL in order to only target hearing-impaired subjects. Using supraliminal test is less impacted by background noise, especially if monitoring background noise is part of the procedure. Finally, technology development that allow for sound attenuation comparable to a booth will allow to replace it. Some authors have suggested using inserts with built-in circumaural headphones in quiet rooms [11] or with passive attenuation devices in addition to the test transducer [12]. Active noise-canceling devices have also been tested [13]. According to Bromwich et al., in an environment with 30 dB of background noise, these devices enable a pure-tone audiometry with a quality equivalent to one carried out in a soundproof booth [14].

Supraliminal audiometry poses fewer technical issues with the sound environment. In any case, the audiometric data can be stored only on a server located in Europe with the Healthcare Data Hosting accreditation from the Health Ministry and in accordance with the European regulation (EU 2016/679) on the Protection of Personal Data (GDPR).

2.1.3. Tele-acoumetry and remote detection of asymmetrical hearing

Tuning fork acoumetry is one of the basic steps in otologic examination, and likely constitutes one of the simplest ways to assess a subject's hearing. With a tuning fork and a trained examiner, the type of hearing impairment can most often be identified. While it obviously cannot replace a traditional audiometric assessment, its results in the context of a pandemic, where they suggest sensorineural or conductive hearing impairment, will help to determine the degree of urgency with which the patient should be treated. Its contribution can be invaluable in the diagnosis of sudden sensorineural hearing loss requiring urgent treatment. Tuning fork acoumetry traditionally combines the Weber test and the Rinne test. The sensitivity of the Weber test when it is carried out alone to detect a unilateral sensorineural hearing impairment is evaluated at between 75 and 80% [15], which justifies the additional

Table 2
Tele-audiometry solutions for diagnostic purposes (CE marked medical devices).

Solution	Product overview	Types of hearing tests	Types of hearing impairments targeted	AC	BC	Masking	Pure-tone audiogram	Speech audiometry	Other functions
Koalys									
Koalys Confirm	Android tablet-based air conduction audiometry; available in French; compatible with Noah data management software	Pure-tone audiogram; Speech-in-Noise	Symmetrical; asymmetrical; unilateral hearing impairments	Yes (headphone with high acoustic insulation)	No	Contralateral (narrowband filtered noise)	AC only Modified Hughson & Westlake Assisted/automated The caregiver indicates if the patient perceives or does not perceive the signal presented (Down 10 dB/Up 5 dB) Self-administered test When the patient indicates that he or she has perceived the signal presented, the level decreases (Down 10 dB) if not, it rises (Up 5 dB)	In quiet Material: lists of mono- and disyllabic Fournier words; cochlear and disyllabic Lafon lists; Lefèvre syllabic lists; paediatric lists Fixed-level procedure for threshold and 100% intelligibility measurements The lists follow each other in steps of −10 dB until the correct repetition score is below 30% Adaptive procedure Initial presentation at 20 dB, then +20 dB, up until the correct repeat. variation ± 5 dB until the intelligibility threshold In noise Fixed-level procedure Adaptive procedure	Video-otoscopy with photo taking Synchronous tele-audiology with management of remote ENT groups Asynchronous tele-audiology allowing after remote transmission of the audiogram a deferred interpretation
Koalys Consult	Computer-based (Windows 10) pure-tone and speech audiometry; available in French; compatible with Noah data management software	Pure-tone audiogram; Speech-in Noise; unaided and aided free field audiometry	Symmetrical; asymmetrical; unilateral; and conductive hearing impairment	Yes (TDH39 headphone, IP30 insert earphones, 2-5 free field loudspeakers)	Yes (B71)	Controlateral (narrowband filtered noise) automated; assisted or manual	AC and BC	Same as Koalys Confirm	Same as Koalys Confirm

Table 2 (*Continued*)

Otohub									
OtoPad	iOS tablet-based audiometry (two channel audiometer; available in French; compatible with Noah data management software	Pure-tone audiogram and suprathreshold audiometry (tone decay, Stenger tests); Speech-in Noise; Free field audiometry; Dichotic test; Tinnitus evaluation	Symmetrical, asymmetrical, and unilateral hearing impairments; Auditory processing disorders	Yes per head/earphones, or in Free Field (TDH39, TDH49, DD45, ER3A, ER5A, ER3 C, IP30, 1 or more loudspeakers)	Yes (B71W)	Contra-, Ipsi-, Binaural (5-dB step sizes) Manual or automatic: Pure-tone audiogram White noise, narrowband noise Speech audiometry Speech Noise (broad-spectrum noise), pink noise	Hughson–Westlake procedure Pulsed, steady and warble tones	AC with masking; auditory processing disorders assessments (dichotic test); "*à la carte*" protocols	Video-otoscopy Synchronous tele-audiology Ipad or smartphone running iOS acts as an audiometer when equipped with OtoPad; direct communication between 2 points takes advantage of the iOS AES256bit encryption for the protection of personal data); minimum internet bandwidth required = 0.5Mbps
Shoebox									
Shoebox Pro	iOS tablet-based pure tone audiometer; available in French; compatible with Noah data management software	Pure-tone audiogram; Speech Audiogram	Symmetrical, asymmetrical, and unilateral hearing impairments	Yes per head/earphones and Insert (DD450, HDA 280, Insert 3A)	Yes (B81)	Manual or automatic; Narrowband noise	Hughson–Westlake procedure 0.125- to 8-kHz pure tone (optional high-frequency testing); manual mode Assisted/automated	Yes (French lists included)	Possibility of gathering audiograms and interpreting them off-line (asynchronous tele-audiology)
eMoyo									
Kuduwave Plus & Kuduwave Pro	Boothless computer-based portable audiometer; not yet available in French	Pure-tone audiogram and suprathreshold audiometry (Stenger test); Speech-in-Noise testing	Symmetrical, asymmetrical, unilateral, and conductive hearing impairments	Yes (earphones under the noise-canceling headphones)	Yes (B71, B71W, or B81)	Yes Automatic Pure-tone audiogram narrowband noise Speech-in Noise testing Speech Noise (broad-spectrum noise)	Air conduction 250 Hz - 8 kHz (can be extended to 16 kHz with vPro); Bone conduction 250 Hz - 4 kHz Optional Stenger test (tuning fork) Manual mode (AC/BC) Automatic mode (Hughson & Westlake; ascending or bracketing method for hearing thresholds determination)	Yes	Synchronous or asynchronous tele-audiology with remote control of the software; option of programming auditory protocols; Tympanometry
Hear X									
HearTest	Pure-tone audiometry app for Android smartphones (Tablet in the future); not yet available in French	Pure-tone audiogram	Symmetrical or asymmetrical hearing impairment	Yes (head/earphones) (IP30 insert + Peltor 3 M headphones/IP30 earphones)	No	No	125 Hz to 8 Hz with option of high frequency testing up to 16 kHz; ascending method, i.e. hearing threshold determined by pure tones at successively increasing levels	No	Possibility of gathering audiograms and interpreting them off-line (asynchronous tele-audiology)

systematic implementation of the Rinne test. A 512 Hz tuning fork with a button is recommended.

2.1.3.1. Weber test. Once percussed, the base of the tuning fork is firmly applied on a centreline point of the cephalic end, typically the middle of the forehead or the vertex. The subject then indicates the localisation of the sound as it is perceived. In the case of normal bilateral hearing or symmetrical hearing impairment, the sound will be perceived in the centre of the head or equally in both ears. In the event of asymmetrical or unilateral hearing impairment with a conductive origin, the sound will be lateralised on the side with the impaired ear. In the event of asymmetrical or unilateral sensorineural hearing impairment, the sound will be lateralised on the side with the better ear. It is recognised that the Weber test thus enables the detection of asymmetries in bone conduction for a minimal interaural difference of 5 dB [16].

2.1.3.2. Rinne test. This test involves assessing the difference in perceived loudness between air conduction and bone conduction for each ear separately, by starting with the ear towards which the Weber test was lateralised, if applicable. Once vibrating, the tuning fork is positioned approximately 2 cm from the external acoustic meatus, its major axis placed perpendicularly to the axis of the external auditory canal. It is held here for 2 seconds. Immediately after these 2 seconds and without interrupting the vibrations, the base of the tuning fork is firmly applied against the mastoid for a further 2 seconds. The subject must then indicate if the sound was perceived as stronger in front of the external auditory canal or on the mastoid. If the sound was perceived as louder through air conduction, the Rinne test is said to be positive, which indicates normal hearing or a sensorineural hearing impairment. In contrast, if the sound was perceived as louder through bone conduction, the Rinne test is said to be negative, indicating a conductive hearing impairment.

2.1.4. Remote transmission and interpretation of brainstem auditory evoked potentials and otoacoustic emissions

2.1.4.1. Brainstem auditory evoked potentials (BAEPs). Most experiments conducted in this area have shown the feasibility, reliability, and effectiveness of interpreting BAEPs via telemedicine [17–19]. The application of BAEPs via telemedicine has primarily been dedicated to helping diagnose neonatal hearing impairment [18]. Real-time viewing is especially useful to determine the reliability of a BAEP wave, once it is close to the threshold and with weak amplitude, because its reproducibility can be judged on its stability throughout its real-time construction.

Prior knowledge of other auditory measures is extremely helpful if diagnosing a suspected auditory neuropathy (ANSD: auditory neuropathy spectrum disorder), because with these patients, BAEPs are altered while the evoked otoacoustic emissions (eOAEs) and the cochlear microphonic potential (CMP) are present most of the time [20].

2.1.4.2. Otoacoustic emissions (OAEs). Click-evoked otoacoustic emissions (eOAEs) have been very rarely used in telemedicine to date. The advantage of eOAEs is that their straightforward data collection gives a result that is not easily confused, based on the recommendations for their correct use and interpretation. The loudness of the signal presented to the ear must be sufficient so that the eOAEs stand out clearly from the background noise, generally around 45–50 dB SPL (sound pressure level) on average with crests around 80 dB SPL. The acoustic quality of the signal supplied must be correct, producing a biphasic intra-meatal signal and not an "accordion" one, which may give rise to too much occlusion of the ear canal and interfere with the cochlear response. The surrounding noise must be low, ideally $\leq$ 40 dB SPL, but a soundproof booth is not necessary. The patients themselves must avoid making "intrinsic" noises (swallowing, sucking, sniffing, etc.) preventing detection of the eOAEs. The number of non-noisy sweeps during the acquisition procedure should be sufficient ($\geq$ 260) before concluding on the absence of eOAEs. However, wide OAEs, standing out from background noise with more than 50% reproducibility, prove that the cochlea functions even with a number of sweeps < 260. The acoustic probe must be stable during data collection.

A recent diagnostic use of eOAEs is to highlight their phase shift depending on the body position of the patient, in the event of hydrops [21]. The signal spectrum must be filtered around 1 kHz (between 800–1200 Hz) in an area where it stands out from the noise. Acoustic phase shift can then be directly measured on the screen (Fig. 3). A phase shift of > 40° between the two body positions, sitting and lying, is pathological. eOAEs can also be used in the same way in the event of suspected intracranial hypertension [22]. The clinical applications of OAEs are quite numerous and likely still underutilised today [23]. Most applications should lend themselves to telemedicine rather easily, following the recommendations above.

2.1.4.3. Distorsion product otoacoustic emissions (DPOAEs). To date, only one team has reported using DPOAEs via telemedicine and only for auditory screening in children [24]. The authors compared the validity of DPOAEs used for screening children and newborns by comparing them to BAEPs also interpreted via telemedicine. However, it is quite feasible to use DPOAEs for direct remote analysis of a possible acoustic phase shift for suspected inner ear or intracranial pressure disorders as with eOAEs, with the aid of body tilt to expose the instability of the DPOAEs' phase [25].

In conclusion, the remote interpretation of acoustic and electrophysiological recordings is feasible and reliable, provided that the person positioning the patient for collecting the signals is trained in it, that verification is possible, if necessary, and that the video-conferencing equipment is of sufficient quality to analyse the waveforms generated in real-time. Nevertheless, we have strong reservations regarding the use of some of these objective measures via telemedicine for complex diagnosis cases.

2.2. Remote training

Simulation is used in many professions for the acquisition of knowledge and skills. Medicine has developed simulation systems, particularly to respect the adage "Never on the patient the first time". Mentoring remains the basis of medical training, and currently it must be accompanied by simulation methods to avoid conducting the first procedure on a patient. This factual situation rests on a recommendation by the French Health Authority (HAS) (https://www.has-sante.fr/upload/docs/application/pdf/2012-01/simulation_en_sante_-_rapport.pdf). Here, we describe remote training courses and the categories of simulators available in audiology. Free live or webinar classes are available in English, (https://www.audiologyonline.com/) as well as lessons (http://audprof.com/). In French, recommendations for the practice of audiometry have been published by the French Audiology Society (https://sfaudiologie.fr/). Such training courses improve students' theoretical knowledge in various areas of audiology, from performing audiometry and objective measures of hearing function to treating patients with hearing impairments, as well as dealing with research topics in audiology.

Websites also provide clinical audiometry cases in the form of online exercises (http://audstudent.com/). Simulation allows students to practice and to learn from their mistakes in a safe environment that is risk-free for the patient. As a matter of fact, training in audiometry is not without risks for the patient. These exist during the procedure (unintentional trauma of the eardrum, noise

Table 3
Different simulation systems available for audiometry.

Type of simulator (required equipment)	Fidelity level	Skills	Immersive	Feedback	On-request creation	Fees	Distributors
Dummy	Weak	Earwax removal	+	–	No	Yes	Ear mould printing
2D simulator (computer + accessories)	Average	Otoscopy	+	–	Yes	Yes	https://www.otosim.com/o
2D Audiometry (computer)	Average	Audiometry Masking	+	–	Yes	No	https://personalpages.manchester.ac.uk/
2D simulator (computer + licence)	Average	Acoumetry Audiometry Masking	+	+	Yes	Yes	http://audstudent.com/ https://www.counselear.com/
2D simulator (computer + licence)	Average	Case history Otoscopy Acoumetry Audiometry Masking Objective audiometry	+	+	No	Yes	https://www.innoforce.com/
Dummy	Average	Otoscopy Earwax removal	++	+	No	Yes	https://www.kyotokagaku.com/
Dummy (+ computer + accessories)	High	Ear impression Hearing aid gain Earwax removal	+++	+	No	Yes	https://www.aheadsimulations.com/carl-for-training
Dummy (+ computer + accessories)	High	Objective audiometry	+++	–	Yes	Yes	http://www.ihsys.com/site/Simulator.asp?tab=5
Virtual reality simulator (+ computer + accessories)	High	Case history Otoscopy Acoumetry Audiometry Masking Treatment	+++	++	No	Yes	Audilab

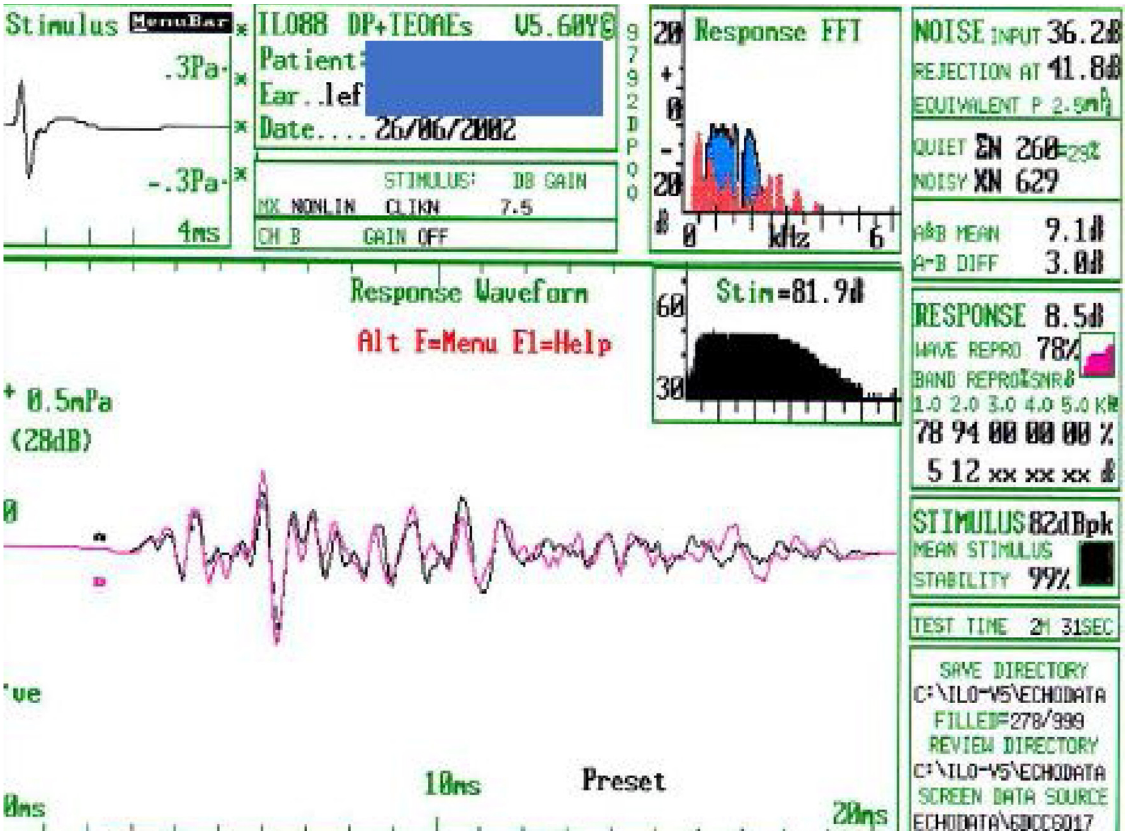

Fig. 3. Screenshot of otoacoustic emissions filtered around 1 kHz (ILO 98) in a patient with endolymphatic hydrops on the left side. The red and black graphs are recorded in the lying and sitting position. The abnormal phase shift here is largely > 40°.

trauma); and after, an inaccurate audiometric diagnosis potentially leading to serious consequences [26] in the event of inappropriate treatment. In addition, audiometry is a difficult examination which brings a lot of knowledge (physiology, mathematics) and skills (procedural, interpersonal) into play. Nevertheless, there are few simulators to develop students' skills in audiometry. Some two-dimension audiometry simulation software can be found online, either free-access or paid (CounselEAR or AudSim, for example). They allow students to train on the research principle of audiometric thresholds, and sometimes otoscopy or tympanometry analysis. Other simulators are more immersive and use low or high-fidelity dummies allowing the student to practice handling an otoscope, or procedures such as removing earwax build-up. However, few of these solutions allow for the total simulation of an audiometry consultation. Interviewing the patient, managing different instruments, analysing imaging and audiometric data to obtain a complete diagnosis, and treatment are all aspects that are not represented in existing simulators. This lack of consideration prevents clinical reasoning. This is why other systems using virtual reality [27], in particular, have been developed to provide an additional training tool for students in audiology, just like flight simulators for pilots. They add an immersive quality and feedback in the event of mistakes. In any event, all of these audiology simulation models allow the students to be better prepared for their future clinical activity. The majority of studies carried out on the benefit of simulation systems, even if there is currently only a handful, have shown an improvement in knowledge and skill scores after simulation sessions [27]. Table 3 summarises the different simulation systems available to date for training in audiology, particularly in the context of students in lockdown.

2.3. Tele-audiology over the lifespan

2.3.1. Decision tree in audiophonology for children

The current development of telemedicine makes it possible to consider expanding the clinical situations in which these remote consultations can be implemented. In the area of audiophonology for children, some teleconsultations could be considered. Several arrangements are possible: i) calling the parents/observing the child via videoconference and sending documents via secure platforms; ii) interaction with health care providers who are trained to use screening tools in case of dedicated programs; iii) verification of audiograms or hearing aid fitting parameters; and eventually iv) remote fitting of cochlear implants. Currently in France, there is no routine teleconsultation programme dedicated to paediatrics. This teleconsultation should be done through adapted, easy to use tools, and through local health practitioners close to the patients. For the moment, therefore, teleconsultation generally only allows for assessing patients, responding to families' questions, and prioritising requests for appointments. There are two aspects to this support.

2.3.1.1. Consultations and interview. To better understand the needs of tele-audiology for children, it is necessary to classify the context of possible requests for consultations. It is particularly important to detect "sensory emergencies" that must be quickly referred to specialised care services: massive speech and language delay in a child over 18 months of age, sudden deafness in older children, post-traumatic deafness, hearing assessment for bacterial meningitis, acute balance disorders in children (Table 4).

Table 4
Child audiophonoloy clinical orientation questionnaire.

Newborn screening	Searching for contexts of severe to profound bilateral hearing impairment	Clinical screening for language-audio effect	Audiometric/electrophysiological examinations already conducted
Yes/no Which type of test eOAEs BAEPs	Failure to pass new-born screening on two occasions Family history of hearing impairment Consanguinity Context of trauma Bacterial meningitis pneumococcus/meningococcus CMV fetopathy Massive speech and language delay in a child aged over 30 months	Parents Thoughts on their child's perception Infant care, siblings Multilingualism Professionals School Preschool, nanny Physician, paediatrician Level of language production Yes/no Articulation disorders Medical context ENT infections and earaches? TT? Psychomotor retardation, stage of speech, presence of dribble, neurology Paedopsychiatry? Speech therapy? Other monitoring and treatments in progress?	Gather the original exams Audiograms BAEPs Auditory Steady-State Response (ASSR) eOAEs

2.3.1.2. Subjective and objective assessment of hearing function. The options for assessing paediatric patients depend on their age. From six or seven years old, outside of complex specific cases, the usual tools and tests for adults can be considered. Between four and six years old, some experiments have demonstrated the possibility of using screening tools (audio screen, tympano screen, screening questions). For the youngest patients, in the absence of local medical services equipped with screening devices (eOAEs, automated BAEPs, or screening audiometer), the consultation focuses on questioning and collecting medical and developmental data, which allows for the preparation of a specialised consultation in the best possible conditions (Table 5).

Table 5
Child audiophonology clinical contexts.

First time, auditory confirmation/opinion	Monitoring a hearing-impaired child (hearing impairment confirmed) or a child who has already been seen
Request for review following newborn screening (0–3 months old) Suspicion of hearing impairment in an infant under 18 months old Suspicion of hearing impairment in a child aged 18 months to 5 years old Speech and language delay in a child aged 18 months to 5 years old Suspicion of hearing impairment in a child aged 6 to 18 years old Sudden hearing loss Opinion for difficulty in noisy environments Opinion for hyperacusis Assessment as part of bacterial meningitis/cytomegalovirus (CMV) fetopathy/cleft palate/malformation syndrome/Karyotype anomalies (including Trisomy 21/Down's syndrome) Assessment before or after otologic surgery or placement of a tympanostomy tube (TT) Assessment before or after chemotherapy, or other ototoxic treatment Hearing examination after a trauma Hearing examination in the context of vertigo or psychomotor retardation Second opinion by an ENT specialist after diagnosis of a hearing impairment Assessment of overall delay, learning disorders, behavioural problems, attention deficit with or without hyperactivity, autism spectrum disorder	Traditional monitoring of a hearing-impaired child with a hearing aid or implant Child with a hearing aid, opinion sought for a cochlear implant Child with a hearing aid, opinion sought for a suspected deterioration in hearing Request for equipment renewal Child with a hearing aid, opinion sought for an aetiological assessment Hearing-impaired child without a hearing aid, opinion sought for how to arrange treatment Monitoring of bacterial meningitis/CMV fetopathy/cleft palate/malformation syndrome/Karyotype anomalies (including Down's syndrome) (hearing-impaired or not) Monitoring after otologic surgery or TT placement Monitoring after chemotherapy, or other ototoxic treatment Monitoring of speech delay

2.3.2. Tele-assessment of elderly subjects

Medical teleconsultation in audiology can be particularly useful for elderly subjects with difficulties travelling for a face-to-face consultation. However, an INSEE (National Institute of Statistics and Economic Studies) survey published in 2019 shows that 15% of those aged 60–74 and 53% of subjects aged 75 and over do not have internet access (https://www.insee.fr/fr/statistiques/4241397). Digital illiteracy affects 17% of the general population, but 27% of those aged 60–74, and 67% of subjects aged 75 and over. This is why it is important to develop networks to help the elderly and those least equipped to use digital tools in order to develop telemedicine. The use of teleconsultation requires the choice of the digital referent: either the elderly person himself or herself, or a relative or caregiver. The different referring care providers of the patient may be involved: general practitioners, geriatricians, healthcare facility advisors, and care providers. ENT physicians, hearing aid dispensers, and often speech therapists are jointly involved in treating hearing disorders.

2.3.2.1. Detecting sensory and cognitive impairments. Among the methods for detecting sensory and cognitive impairments, there are several tools available. They should be easy and quick to use. At least two methods have been developed: questionnaires and remote hearing screening tests. The AVEC (*Audition Vision Équilibre Cognition*: Hearing Vision Balance Cognition) questionnaire (see Online material) is a detection kit that can be used by all care providers [28]. It relies on four pillars: two self-administered questionnaires on hearing and vision, the results of which determine referral to the ENT physician for clinical and audiometric evaluation, or to the ophthalmologist; an assessment of balance using the unipedal stance test, and a cognitive test, the Codex [29], which allows for a decision on the need for specialised assessment (Geriatric consultation, Neuropsychological assessment). The AVEC test expands detection beyond hearing impairment alone: it allows for an individual hierarchy of priorities in the process of treating sensory impairments and their cognitive impact, as well as quality of life. Audiometric assessment tests in the form of self-administered screening tests have been outlined above. Their adaptation for the characteristics specific to elderly people must be taken into account: in particular, attention span and level of alertness.

2.3.2.2. Formalisation of diagnosis and treatment orientation. After detection and depending on the circumstances, diagnosis can be carried out face-to-face or via teleconsultation, using the tele-otoscopy and tele-audiometry methods outlined above. They are adapted to the specificities of elderly people. This allows for the identification of different audiological situations where further investigations are sometimes necessary (objective tests, imaging, etc.). At the end of this stage, hearing aids are prescribed if needed, potentially associated with speech and language therapy, which can be performed with digital tools.

2.3.2.3. Monitoring patients presenting with a hearing impairment. Teleconsultation can ensure that the patient is wearing and maintaining their hearing aids, reminding the patient and their close ones of the need to wear the hearing aids at all times and to have it maintained regularly by the hearing aid dispenser. This can be adapted and coordinated in healthcare facilities where professionals, particularly hearing aid dispensers, are called on. This consultation can remind the patient of the negative impact of hearing impairment on cognitive function and quality of life, with an increased risk of social isolation and depression, in order to enlighten them and their caregivers as to the benefit of hearing rehabilitation [30]. In a subject with a cochlear implant, teleconsultation can take place between 2 adjustments in order to ensure that the processor(s) are being worn and maintained regularly and to remind them of what they should do in the event of the processor malfunctioning. Teleconsultation may be an opportunity to suggest continuing speech and language therapy or taking it up again; this is possible through telecare via videoconferencing during the COVID-19 pandemic for patients who are already being followed-up. Different publications have demonstrated the feasibility of tele-audiology methods for elderly people, for monitoring people with implants, and in particular for adjusting devices [31,32].

3. Conclusion

The development of tele-audiology is occurring in a context where the physician and the surgeon must, in many clinical situations, measure the loss of chance that would result from a failure in diagnosis, surveillance, or treatment. With the COVID-19 pandemic, after the necessity of stopping ongoing and scheduled medical consultations for a time, except for emergencies, it is now necessary to treat ill people at risk of "loss of chance". From a medical standpoint, loss of chance can be apprehended through its cause, namely diagnosis, treatment, monitoring, etc., because any delay can be qualified as loss of chance. As such, loss of chance becomes the privileged domain of dereliction of duty (by delayed diagnosis, by negligence in the prescription of additional examinations, etc.). The medical approach to loss of chance includes three concepts: the possibility of better results than dereliction (diagnosis, treatment), respecting the patient's rights (reaffirmed by the French law dated 4 March 2002) and the assessment of loss of chance as per bibliographic documents (recommendations from learned societies, cohorts studied, and spontaneous development). To suit the subject matter, the concept of "loss of chance" has become "loss of chance of recovery or survival". Loss of chance is halfway between damage and causality. It does not stand in for the causal link but makes up for the disappearance of a likelihood of refusing a treatment, achieving a recovery, or suffering less harm. In this outbreak context, the new telemedicine tools undoubtedly help limit this loss of chance, making it possible to ensure even more regular follow-up [33]. In a recent telemedicine experiment conducted in ENT during the COVID-19 pandemic, it was reported that otological and audiological symptoms (otalgia, hearing impairment, dizziness) were the most frequent reasons for teleconsultation [34]. Tele-otoscopy, an essential prerequisite for any teleconsultation in otoneurology [35], is a telemedicine tool that has already proved its worth. However, the regulations in force make its use still marginal in France and an evolution of this latter appears essential if we wish to be able to extend it on a larger scale. Technical solutions already exist to remotely perform both subjective and objective assessment of the patient's hearing function.

Disclosure of interest

The authors declare that they have no competing interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.anorl.2020.10.007.

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