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ACOUSTICAL ENHANCEMENT OF TELEMEDICINE / TELEHEALTH IMPLEMENTATION IN MEDICAL FACILITIES

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Telemedicine or telehealth medical consultation is increasing dramatically due to increase in smart-phone and virtual meeting technology. At the same time, global pandemic restrictions on travel and personal interaction compelled medical service providers to accept alternate forms of remote communications from patients. ECRI, a patient safety organization has included rapid adoption of telehealth technologies in their top ten technology hazards for 2021. To improve remote medical consultations, The Facility Guidelines Institute (FGI) Acoustics Proposal Review Committee (APRC) is developing telehealth principles and direction for the FGI 2022 edition. Telephonic speech intelligibility may be degraded depending on ambient background noise, hearing acuity and poor or lacking visual and tactile cues. Hearing impairment and/or second-language speech further degrade comprehension. Dedicated telehealth facilities may be developed where acoustical conditions can be optimized to enhance remote speech and hearing, but telehealth communications from non-optimized spaces may be compromised by transient activities, speech or other noises. At the receiver end of the communication, remote patient acoustical conditions may impose critical constraints. Speech interference should be limited through control of transient intrusive noise events. Conditions for virtual presence should be optimized, such as microphone proximity, lighting, view angle and distance between camera and subject. Acoustical criteria are presented in this paper with guidelines for telehealth room or facility design and construction. A proposed checklist is introduced for controllable room conditions for patient and medical service provider ends of the remote consultation. Also, pre-call preparations need to be developed along with post-call follow-up to confirm comprehensions of medical issues, recommendations, prescriptions and other telehealth consultation outcomes.

Keywords: FGI, Telemedicine/Telehealth, Intelligibility, Noise, Privacy, Reverberation

1. Introduction

Everything old is new again, a commonly repeated phrase over time, applies to telemedicine or telehealth medical consultation. Alexander Graham Bell is said to have made the first telephone call for medical help in 1876, and the *Lancet* in 1879 cited a case of a late-night call to a doctor regarding a cough and his response after hearing it over the phone [1]. Many reports of medical and diagnostic communications are described in a comprehensive and well-documented Nesbitt & Katz-Bell history of telehealth [2], including significant development by universities, government agencies, NASA, the Veterans Administration and others in the 20th century. Telemedicine use is expanding dramatically due to increase in smart-phone and virtual meeting technology, further emphasized by the global pandemic limitations on social interaction.

More contemporaneously, care provision to rural and isolated populations, avoidance of travel and loss of time during critical medical events have resulted in expansion of the volume and types of service, such as physician-patient video and audio, transmission of diagnostic data, etc. Exponential rates of development and innovation pushed telehealth into the mainstream, as evidenced in the growing body of scholarly and technical literature on telehealth, telemedicine and digital health over the last decade [3]. There is some evidence that “telemedicine promotes continuity of care, decreases cost of care, and improves patient self-management and overall clinical outcomes.” Between clinic visits, telemedicine can assist identification and/or prevention of treatment-related errors [4].

Telehealth may not be a panacea, however. ECRI, originally Emergency Care Research Institute, a patient safety organization has included rapid adoption of telehealth technologies in their 14th annual top ten technology hazards for 2021 [5], possibly leaving patients and data at risk. As organizations transition to the new telehealth delivery models, “programs may struggle to provide sufficient user training, to coordinate patient care, or to overcome technology resource inequalities among patients.” In this light one might reasonably conclude that ample opportunities for medical error or patient misunderstanding may occur with two-way remote audio and video communications. A report by The Doctors Company on risks of telemedicine cited different diagnosis and treatment issues, and found in a related study that diagnostic errors are the most common allegation in telemedicine-related (medical liability) claims [6].

Many developments in telephonic and digital communication s platforms have improved telehealth, and much has been written about what types of equipment and systems are appropriate for different purposes or conditions and what to consider [7]. However, patient hearing loss, poor speech intelligibility of transmitted audio and speech interference caused by transient noise significantly diminish possibilities of successful telemedicine outcomes.

Recent statistics indicate that hearing loss may be the third most common chronic condition in the United States, with hearing loss in one or both ears in 1 of 13 adults 50-59, and increasing to 2 of 3 adults of 70 years or older. With an aging population, hearing loss is expected to nearly double over the next 40 years [8]. Many older patients and some physicians surely must have some difficulty understanding telephone or other audio speech. Continuous background noise and reverberation make speech less intelligible, while transient noise events interfere with speech [9]. Therefore, room acoustic conditions limit effectiveness of two-way audio transmissions between physician and patient.

2. Proposed FGI guidelines for telemedicine in 2022 edition

The Facility Guidelines Institute (FGI) produces Guidelines for Design and Construction (for health care facilities), which is adopted as code in many states and countries, and referenced as “good practice” basis of design in others. Criteria are incorporated for building acoustics, noise and vibration control [10]. To improve remote medical consultations, The Facility Guidelines Institute (FGI) Acoustics Proposal Review Committee (APRC), of which this author is a member, is developing telehealth principles and direction for the FGI 2022 edition, which primarily relates to telemedicine rooms or facilities, and secondarily to their use. To optimize telephonic or digital speech interactions, it is desirable to strictly control acoustic conditions in the physician space, and to improve conditions in the patient space to the extent feasible. Parameters to be controlled include sound isolation for speech privacy and freedom from intrusive noise, continuous background sound and reverberation [11]. In addition, microphone location and distance from person speaking affect speech clarity [12]. To aid visual cues in the video transmission, camera placement and gaze angle, adequate and level illumination levels, direct and indirect back lighting and fill lighting, and background surfaces (simple or visually busy) can either limit or improve video facial view of participants [13]. Ultimately, visual and audible signals are critical to successful outcome for video-conferencing telemedicine between caregiver and patient.

3. Acoustical and noise control criteria and guidelines

3.1 FGI acoustical criteria

Telemedicine rooms or facilities will be added to FGI interior acoustical criteria in the 2022 edition as summarized in Table 1, below (exterior site noise criteria are excluded here). There are three volumes of FGI, for i) hospitals, ii) outpatient and iii) residential facilities. The criteria and guidelines for telemedicine rooms in FGI 2022 will be very similar in each volume. Proposed 2022 additions for Telemedicine [14] include:

- 1.2-4: Minimum Design Room Sound Absorption Coefficients, $\overline{\alpha}$ = 0.25.
- 1.2-5: Maximum Design Criteria for Building Systems Noise = NC-25, 30 dBA.
- 1.2-6: Design Criteria for Minimum Sound Isolation Performance Between Rooms, *STCc is not specified for telemedicine, but Consultation, Exam and similar are STCc 50 for speech privacy, or STCc 60 to prevent noise intrusion from imaging or building equipment rooms.*
- 1.2-7: Design Criteria for Speech Privacy - Enclosed Rooms = Confidential (PI, AI, SII, SPC)
- 1.2-8: Maximum Limits on Floor Vibration Caused by Footfall (impacts) = 8000 μ-in/s.

Table 1: Summary of FGI Acoustical, Noise and Vibration criteria for Telemedicine

Space Category	Room Type*	$\overline{\alpha}$	NC/dBA	STCc	Speech Privacy	μ-in/s
Diagnostic & Treatment	Telemedicine	0.25	25 / 30	50-60	Confidential	8000

* *Sound-isolated Telemedicine rooms are recommended. Table 1 does not apply to open spaces.*

Dedicated telehealth facilities may be developed where acoustical conditions can be optimized to enhance remote speech and hearing, but telehealth communications from non-optimized spaces may be compromised by transient activities, speech or other noises.

3.2 Criteria application guidelines

3.2.1 Space planning

The telemedicine function should be free of transient noise and movement from unrelated parties. The room should accommodate no other clerical, administrative or medical functions or personnel. Unique, purpose-built rooms accommodating only telemedicine equipment and functions are recommended; not multipurpose spaces that may permit distraction from unrelated simultaneous speech or activities.

During the early design process, consideration should be given to avoidance of incompatible lateral or vertical space adjacencies for telemedicine rooms, i.e., floor-to-floor and room-to-room. In addition, since the nature of the teleconference-telemedicine space does not require exterior views, interior location in lieu of along perimeter window glazing can reduce intrusion of exterior or environmental noise. Therefore, telemedicine room locations should be separate or buffered from high-noise spaces. Only acoustically compatible quiet rooms or functions should be considered for adjacent space assignments.

3.2.2 Acoustical demising envelope

Acoustical demising assemblies enclosing the telemedicine room are assumed to extend from floor to structural deck above, and should be designed or selected to provide speech privacy as well as freedom from intrusive noise originating in adjacent spaces. FGI permits a lower STCc 35 for room partitions with corridor entry doors, but provision of maximum feasible entry door sound isolation should be considered for telemedicine. Although not recommended, if telemedicine room partitions extend only to ceiling elevation, leaving an open plenum, the room ceiling becomes a critical part of the demising assembly envelope, and should have minimum CAC ratings $\geq$ 35, but preferably > 40. In addition, all ceiling openings and penetration require closure or sealing to contain sound.

3.2.3 Partition selection and design

If the space planning function fails to separate telemedicine from building systems or medical procedure spaces with mechanical, electrical, plumbing or HVAC equipment, walls and/or floor-ceiling assemblies should have STCc ≥ 60, but particular attention needs to be applied to achieving octave band transmission loss (TL) adequate in specific bands where the building or medical equipment radiates maximum noise, e.g., if the equipment room noise source has a tonal prominence in the 250 Hz octave, the transmission loss of the demising assembly in the 250 Hz band should be great enough to prevent exceedance of the noise criteria (NC, see Table 1) for the telemedicine room. If there is significant floor or wall vibration in the equipment space, decoupling of demising elements and/or damping of wall surfaces should be employed to mitigate audibility due to vibration-caused room surface radiated noise.

If space planning results in public or other support areas adjacent to telemedicine, including waiting, labs, nurse stations, administrative or other space with moderate background noise, STCc ≥ 50 is required. Adjacent quiet rooms, such as conference, examination, treatment, physician or private office, STCc 50 is required, but special attention is necessary to assure no flanking pathways, such as common air conditioning duct connections, window mullions at demising partition, inset boxes for electrical junction, video monitors or other device, other partition penetrations or inset boxes in floor slab. Common framed drywall partitions with single layers of gypsum board on each side of the stud, with or without sound attenuation blankets (SAB) in the framing cavities cannot generally achieve STC 50. For speech privacy, performance increases with variations:

- light, 20-22 gage metal studs in lieu of structural gage metal or wood studs
- stud-framing spacing at 24" o.c. (600 mm) in lieu of 16" (400 mm)
- decoupled or double stud framing and/or resilient drywall mounting devices
- internally damped drywall products; damping layer laminated between gypsum layers
- multiple layers of drywall product on one or both sides of the framing studs, or alternately, other mass layer, such as mass-loaded vinyl between stud and gypsum layer.

3.2.4 Doors and acoustical seals

Doors are weak points in a sound isolated room envelope. While FGI permits derating room partitions with corridor entry door to STCc 35, the door and frame performance generally needs to be STC ≥ 29. Doors with no acoustical seal are about STC 20-23. Doors with dust, smoke or air infiltration seals are not much better. To achieve performance approaching STC 30 or better, door stop, head, bottom and astragal seals labelled for acoustical performance should be specified and installed. Some seals are labelled for multiple services, such as dust or smoke and acoustical. Those can be acceptable, also.

3.2.5 Interior glazing sidelights and windows

Interior windows and sidelights also significantly degrade demising and corridor partition sound isolation performance. For speech frequency, sound transmission loss (TL) in 500 – 2000 Hs frequency span of the audible spectrum is critical, since consonant sibilance is within that frequency range [15]. Plate and tempered glass have characteristic "coincidence" dips in frequency response performance within the 1000-2000 Hz frequency span [16]. Use of laminated glass can mitigate that performance deficiency. Alternately, optical grade acrylic can provide better sound transmission loss in speech frequencies. Double-pane insulated glass provides only a small incremental improvement if both panes are the same thickness, but transmission loss performance improves slightly if the glass fixture is unbalanced (asymmetrical) with different pane thicknesses. Of these alternates, laminated glass is preferred.

3.3 Building systems noise control

Building systems may incorporate central plant, various mechanical, electrical and plumbing systems, elevators and back-up power generation. Within occupied interior spaces, heating, ventilation and air conditioning (HVAC) is the dominant and often most proximate background noise source. Within telemedicine rooms, the background noise for relatively continuous noise should not exceed NC 25 or 30 dBA (re: Table 1) to optimize speech intelligibility of the communication audio or to minimize speech and microphone interference. Transient, off/on or modulating noise from HVAC equipment or components should be permitted no more tolerance than +/- 3 dB from the continuous noise criteria. ASHRAE is the source for FGI building systems noise criteria. HVAC noise data and procedures for analysing and predicting noise from building systems may be found in ASHRAE HVAC Applications Handbook, Noise and Vibration Control chapter [17], 2011, ’15 and ’19 editions.

When evaluating building systems noise within the telemedicine room, consider all contributing sound sources and the additive effects of multiple sources [18]. The manufacturers’ radiated sound ratings from supply air diffuser, return air register, and any air terminals or other elements located in the ceiling plenum should be at least 3 dB less than NC-25 for each contributing element, because if sound sources individually approach NC 25, the net room level will exceed the recommended maximum background noise criteria. In addition, evaluate ducts and demising assembly penetrations for pipes, conduits or other attachments as sound flanking pathways or leaks that derate the sound isolating properties of partitions.

Air conditioning and heating supply and return ducts or return transfer ducts provide sound conduits between interconnected rooms. Provide acoustically lined or acoustically rated flexible ducts at supply register and return register connections in the ceiling. Ducted return air is preferred for telemedicine, but if only return air transfers are installed, they shout go to (quiet) corridor or utility space in lieu of transferring between two quiet occupied rooms.

3.4 Speech privacy in enclosed rooms

Speech privacy is essentially the reduction of intelligibility of speech to the point that phrases, sentences or paragraphs transmitted from a space cannot be understood. From an enclosed room speech source sound or airborne sound is transmitted through the acoustical demising assembly (wall or wall + ceiling) to the adjacent or receiving space, where it may be heard. Speech interference or masking determines intelligibility or privacy, which is a function of the level, spectrum and continuity of background sound in the receiver space. While FGI presents multiple speech privacy metrics, PI, AI, SII and SPC, re: FGI Table 11.2-7, which may be calculated with measured data, in some respects all involve source sound, demising noise reduction and receiver background sound. For evaluation in design, speech privacy potential (SPP) [19] or total acoustic separation may be estimated by adding STC + NC for the receiver, e.g., if the room or corridor outside telemedicine is NC 35 and the demising partition rating is STC 50, the resulting sum of 85 represents a very high degree of privacy or approximately how loud the source speech would need to be to be heard and understood at the receiver location. If one assumes background varies some with time and demising field performance is derated -5 STC points, the conservative estimate might be 30 + 45 = 75 dB separation.

Where the demising assembly or envelope of the telemedicine room and the continuous broadband sound in the adjacent room, open space or corridor is relatively quiet, sound masking may be considered to supplement speech privacy by raising continuous background sound in the spaces outside or adjacent to the telemedicine room, but not within the telemedicine room. FGI recommends masking within enclosed rooms (offices and similar) not exceed 42 dBA and masking in corridors and open spaces not exceed 48 dBA. Use somewhat lower masking sound levels if adequate speech privacy can be obtained [20].

3.5 Telemedicine Interior Room Acoustic Design

Room volume, shape and surface finishes determine reverberation decay time (T60) and reflection patterns within the telemedicine room. Designers should remember that the room acoustics affect the microphone and outgoing audio transmission to a greater degree than what may be perceived by occupants in the room. Reverberation can muddy or slur the speech, reducing clarity and intelligibility. Undesirable reflections may cause speech interference, or in some cases, contribute to microphone feedback noise. FGI recommends an overall room absorption coefficient, (Table 1) based on Noise Reduction Coefficient (NRC), $\overline{\alpha} = 0.25$, for estimating the design room-average sound absorption coefficient. This is the summation of absorption coefficients of each surface material multiplied by the surface areas of each material, and the result divided by overall room surface area [21].

In a practical sense, for small rooms of 1000 ft^3 area (29 m^3) to 2000 ft^3 area (56 m^3) volume, the FGI recommended room absorption can be achieved with only an NRC $\geq$ 0.70 acoustically absorptive ceiling, but achieving the telemedicine room FGI recommended room absorption is more likely to require some wall absorption in addition to the acoustical ceiling. Carefully placed wall absorption also may be used to control reflection patterns. Undesirable reflections called flutter echo occur between parallel wall surfaces. Sound entering 90° corners reflects back to its origin. Longer path standing waves may occur between diagonally opposite floor and ceiling corners of a room. Where feasible, it is desirable to design and construct the telemedicine room with non-parallel walls, but that is often difficult in the room layout.

Given that most rooms in a rectilinear structural grid are rectangular, they have 90° corners and parallel wall surfaces. Since video display screens and individuals in the room may interfere with front-to back reflections, the most effective locations for wall absorption in the telemedicine room are side walls to reduce flutter echo. If the side wall absorption can be near or extend to room corners and up to ceiling elevation other diagonal reflections can be controlled. The overall surface area of wall absorption can be minimized and remain effective if it is at the elevation of occupant ears, (speaking) mouths and microphones. Therefore, the absorption is recommended from approximately 30” (760 mm) above finished floor (work surface height), up to approximately 78”-80” (2 m) above finished floor (door head height).

3.6 Remote Patient Interior Room Acoustics

Since the remote patient location is not in the control of the physician or the health care facility, it may not be possible to control room acoustics, sound isolation/privacy and/or background noise where the patient is located while participating in teleconference style telemedicine consultation, but several measures may be suggested to the patient or patient’s caregiver. Use a telephone, computer, tablet or other digital device in a room that is isolated from other household or residential facility activities and speech. Do not permit other people, machines or equipment to be in the same room or vicinity. Provide acoustically absorptive items such as window drapery, blankets, pillows, etc. around or near the teleconferencing device. Avoid use of room fans or other noise making devices while the telemedicine consultation is in progress. Provide adequate lighting on the patient’s/subject’s face. Conduct a pre-consultation call with the patient or care giver to discuss and arrange the space for optimization of speech intelligibility, to improve telemedicine outcome success.

4. Proposed FGI Telemedicine Acoustics Checklist

Two coordinated telemedicine checklists are proposed by a subcommittee of the FGI APRC [22]. As currently drafted in design, they will provide brief descriptions of “actions” that should be undertaken by “provider” and by “patient,” with short itemized “application” descriptions or directions. Items are included for the provider, such as a written set of instructions before the call, test call, choice of quiet places and reduction of background noise, ensuring good appearances and good audio while maintaining speech privacy. Actions on the patient list also include ensuring ability to hear and understand the audio and suggested tools for hearing assistance. A suggestion is included for follow-up call recording to confirm comprehensions of medical issues and to reinforce or remind patient and/or care giver of recommendations, prescriptions and other telehealth consultation issues or things to do.

5. Conclusions

Consideration of anticipated FGI criteria for telemedicine/telehealth facilities and careful application of practical design guidelines to control room acoustics, sound isolation/privacy, continuous background noise and intrusive transient noise can result in optimal remote communications facilities, resulting in fewer medical errors and better overall healthcare outcomes.

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