Pediatric Applications of Telehealth Technology and Evoked Otoacoustic Emissions

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Telehealth, or telemedicine, is the provision of health care services using a telecommunications medium (American Speech-Language-Hearing Association, 2005; Ricketts, 2000; Wootton, 2001). Specifically, telehealth indicates that practitioner services are provided to patients using an electronic medium such as a computer network, the telephone, satellite or two way radio (Mun & Turner, 1999; Stanberry, 2000). Telehealth services are used to serve people with limited healthcare access who typically live in rural or inner city communities.

Applications have advanced substantially since the first telehealth services were explored. Also, it is likely that the most important telehealth advancements have occurred in the past decade spurred by lower interactive video costs and the advent of powerful but affordable personal computers. In addition, the greater accessibility to cost effective Internet services, and rapid computerization of medical devices are important contributing factors leading to telehealth service development.
Terminology.

Although telehealth is a common term, similar terms are often used today. These terms include telemedicine, e-care, e-health, telepractice, and telecare. Telemedicine is frequently used to describe physician and other medical services. In contrast, telehealth is more broadly defined to include those services provided by allied health-care professionals and by physicians alike. This view led to the Comprehensive Telehealth Act of 1997 in the United States in which all health care services provided over a telecommunications system were defined as telehealth. It is with this perspective that the term, telehealth, will be used for the remainder of the paper.

A brief history of telehealth.

Telehealth is over a century old (Stamm, 1998; Stanberry, 2000). While the first telehealth service was not documented, it was probably conducted using a telephone (or the telegraph) and was likely a consultation. In the early 1900’s, maritime telehealth services were provided to sailors on ships from land based physicians using two-way radio. It is interesting that similar maritime telehealth services continue today even though the transmissions are likely satellite based in most cases. In the 1960’s, the National Aeronautics and Space Administration (NASA) used telehealth technology with astronauts to measure vital signs and radiation exposure while in space. Because of the continued need to provide care to individuals in remote locations, telehealth services are commonly used in many professions, including cardiology, radiography, otology, pediatrics, pharmacology, psychology, psychiatry, and speech-language pathology (Blackham, Eikelboom, & Atlas, 2004; Krumm & Sims, 2011; Nickelson, 1998; Perednia
Telehealth models.

Telehealth services can be delivered by synchronous (real-time) or asynchronous (store and forward) methods. Synchronous data communication is typically conducted via interactive video and can be augmented by information sent in an asynchronous mode. In contrast, asynchronous telehealth services require that patient data has been recorded first at the patient site and then, after some period of time, sent electronically to the clinician for interpretation. Asynchronous procedures are commonly employed when there is inadequate bandwidth for synchronous procedures. In addition, asynchronous applications may be utilized when time is less of a concern regarding the diagnosis or when the clinician is unavailable to conduct services. Finally, analog equipment which cannot be used for remote computing purposes, often can be gainfully configured for asynchronous applications. For example, an old tympanometer, which can only print out immittance results, can still be used for asynchronous applications by scanning patient immittance results into a computer and sending the data (via email attachment) to an audiologist for interpretation.

Asynchronous telehealth technology.

Asynchronous data transfer is probably used by audiologists today and may in fact be a common practice. Specifically, this form of telehealth technology is utilized when information such as tympanograms, audiograms, auditory brainstem response
recordings, or video-otoscopy images are transmitted via E-mail or by fax (see Figure 1).

Asynchronous applications are commonly used to provide practitioners with patient information (printed results, digital photos or video clips) using email, fax or Internet video applications.

Asynchronous studies have been published evaluating the efficacy of telehealth with tympanometry, video-nystagmography (VNG), and video-otoscopy (Birkmire-Peters et al, 1999; Yates and Campbell, 2005). In addition, E-mail communication was used to deliver cognitive-behavioral therapy for tinnitus treatment (Kaldo-Sandström et al, 2004) and for counseling new hearing aid users (Laplante-Lévesque et al, 2006).

One appealing asynchronous application is self-assessment of hearing sensitivity. Presently, self-assessment procedures involving hearing testing online appear to suffer from questionable calibration, poor validation, and the lack of control over environmental noise levels. Nevertheless, as this is an emerging area of audiology telehealth, it is likely problems associated with self-assessment will be solved in the future.
Synchronous services.

Synchronous services are characterized by the clinician delivering services to clients in real time or “live” (See Figure 2). Such services may include the use of online chat, the telephone, interactive video, or remote computing technology. Interactive video is typically utilized with synchronous services to observe client responses to stimuli and to assure clinicians that audiometric equipment (transducer, probes, and electrodes) are properly placed. Interactive video may be provided by a laptop Webcam or by a dedicated camera system that is interfaced directly to the computer network. While interactive video can require substantial bandwidth, the benefits are obvious, providing the clinician and patient with services that are essentially “face-to-face”. High costs have limited routine use of interactive video but it is increasingly available and affordable in rural communities.

Audiologists may use two models of synchronous telehealth models. The first model is the traditional model used in other professions. This model requires the extensive use of high-quality interactive video in which the clinician supervises testing by a technician at the remote site. Once the technician obtains patient data, the clinician will typically provide a diagnosis and recommend management. This model has already been used successfully by Marincovich (M. Marincovich, personal communication, April 5, 2009) to provide hearing evaluations and hearing aid fittings in a rural region of California in the USA. For this model to be effective, the technician must be trained well enough to administer, but not necessarily interpret, audiology test results. Rather, interpretation and counseling is done by the audiologist. This is an effective solution when the technician turnover is low and ongoing technician training is possible. Also, the
traditional model has the benefit of comparatively modest technology requirements.

Synchronous services

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Figure 2. Synchronous services using interactive video

Another form of synchronous audiology services incorporates remote-control in so that clinicians can test patients at distant sites. This is a reasonable telehealth strategy to consider as many audiology systems are computerized, utilizing a Windows platform; and as a result can be incorporated for remote computing applications. Consequently, a clinician at one site can control computerized audiology equipment at a distant site using application sharing software through a network, modem or the Internet. The greatest advantage to this method is that a technician is not required to do testing at the patient site. However, a technician is still required to do tasks such patient basic instructions, transducer placement, otoscopy, and have some skills in running the computer at the patient site. Figures 3 and Figure 4 show the equipment that is typically used with a
synchronous program.

Figure 3. The clinician equipment configuration for an audiologist administering telehealth services. Note only a computer (with remote computing software) and a webcam is required at the clinician site.

1. Using this paradigm, investigators have employed synchronous protocols to administer a variety of common hearing tests to subjects including pure tone, speech, otoacoustic emissions and the auditory brainstem evoked response (Choi, Lee, Park, Oh, & Park, 2007; Givens & Elangovan, 2003; Krumm, Ribera & Klich, 2007; Ribera, 2005; Swanepoel, Koekemoer & Clark, 2010, Towers, Pisa, Froelich, & Krumm, 2005).
Figure 4. Equipment required at the patient site. For remote computing purposes, a computer, webcam or dedicated camera, computerized audiometric equipment (an audiometer is pictured), video-otoscopy, immittance (not shown) and a LAN connection would permit basic audiology telehealth services.

In addition, synchronous technology has been utilized to program cochlear implants (Franck, Pengelly & Zerfoss. 2006; Ramos et al., 2008), program and verify hearing aids functioning (Fabry, 2004; Ferrari & Bernardez-Braga, 2009; Wesendahl, 2003) and to provide neural response/telemetry assessment (Shapiro, Huang, Shaw, Roland & Lalwani, 2008). This telehealth technique presently requires further validation but has been used successfully to administer hearing tests over considerable distances (Krumm, Ribera & Klich, 2007; Ribera, 2005; Towers, Pisa, Froelich, & Krumm, 2005).
The hybrid model.

While the sole use of asynchronous or synchronous technology appears to be reasonable in some circumstances, audiologists should consider the most efficient system to deliver telehealth services. In many cases, a combination of synchronous and asynchronous technology will yield the best solution for hearing health-care services. This combination of technology is considered a hybrid model and is regularly used in many telehealth programs.

Telehealth services and otoacoustic emissions in adults. Evoked otoacoustic emissions (EOAEs) have obvious applications for hearing assessment and, therefore, it is not surprising that investigators incorporated EOAEs in early audiology telehealth research. The first of these studies was a master thesis written by Schmiedge (1997) assessing the validity of DPOAEs recordings using synchronous methods. In this investigation, an Apple (Power PC) computer system was interfaced to a computer peripheral capable of generating and recording DPOAEs (Virtual Systems model 330, version 1.9). Timbuktu desktop remote computing software was installed on the computer controlling the DPOAEs for remote computing (synchronous) purposes.

Subjects assessed in this study were college aged students who exhibited normal hearing sensitivity and no significant history of hearing loss. These subjects were tested in a sound treated booth equipped with the Virtual DPOAEs system connected to a high speed computer network and to a modem. An audiologist (in the same building as the subjects) operated another Power PC computer equipped similarly as the subject computer and, therefore could control the subject DPOAE system using the computer network or modem. Subjects’ DPOAE amplitudes were obtained and compared in the
following conditions: face-to-face in a “typical” clinical condition with an audiologist; through a modem connection capable of achieving a 33,600 baud/second connection; and through a high speed local area network (LAN) connection. DPOAE recordings were obtained in 1/3 octave intervals in the frequency range of 1000-4000 Hz using an f1/f2 ratio of 1.21 and a stimulus presentation of 65/55 dB SPL.

Results of this study revealed high agreement of DPOAE means and standard deviations between face-to-face, modem and LAN conditions. The outcome of these data suggested that DPOAE recordings could be accurately measured using telehealth technology with “off the shelf” otoacoustic emissions system hardware and desktop remote computing software. However, in this study there were problems with recording DPOAE data. Computer recordings of DPOAE data would be somewhat unstable during both telehealth conditions and would periodically result in corrupt DPOAE recordings. A caveat is that corrupt data is always possible and should remain a concern.

Following this work by Schmiedge, a paper was published by Elangovan (2005), describing a customized otoacoustic emissions system developed for synchronous telehealth applications. Elangovan found that this system produced comparable distortion product otoacoustic emission DPOAEs results for five adult subjects when telehealth and face-to-face comparisons were made. Although the outcomes for the otoacoustic emissions systems were impressive, the investigators made their measurements in the same location of the subjects. Consequently, further validation was needed at a distance to determine the value of the system described by Elangovan.

The first research which demonstrated that EOAEs could be measured at a substantial distance was published by Krumm at. al (2007). In their study Krumm et al.
(2007) utilized an off-the-shelf computerized Biologic Scout EOAEs system and a low cost video-conferencing system to record DPOAEs in 30 adult subjects. The EOAEs system was interfaced to a PC connected to a LAN at the subject test site. A second PC was used to provide telehealth services at approximately 1000 Kilometers (Km) away from the subjects. PCs at both sites, running the Windows 2000 operating system, were configured with an interactive video system (VIGO, Emblaze-Vcon, Hackensack, New Jersey) bundled with Meeting Point 4.6 video conferencing software. Remote computing was made possible by application sharing software bundled within the Meeting Point program. A schematic of this system is found in Figure 5. Results of this suggested that the synchronous measurement of DPOAEs over long distances was feasible as telehealth and face-to-face DPOAE measurements were equal. Further, no technical problems occurred that were described earlier by Schmiedge (1997).

![Figure 5. A schematic of the DPOAE system used by the author for synchronous DPOAE research over a distance.](image-url)
Telehealth and DPOAEs measurements in Infants.

In all likelihood, EOAEs in telehealth will be used with infant and young children involved in an early hearing detection and intervention (EDHI) program. But EDHI program goals can be difficult to achieve due to inadequate professional expertise, lack of program planning and insufficient funding ((Mencher, Davis, Devoe, Bereford & Bamford, 2001). Also an EDHI program should exhibit continuity of services up-to-date information, operate as a community-based health program, and provide accurate tracking information for newborns requiring further screening or assessment (Mencher et al., 2001). O’Neil, Finitzo, and Littman (2000) addressing similar EDHI issues suggested new paradigms should be developed to insure that each infant is provided needed services regardless of circumstances.

Such a paradigm may incorporate telehealth services. Telehealth has been an effective medium of providing medical expertise to isolated communities and is a common practice in many health care professions.

One intriguing nature of EOAE systems is that many of these systems are commonly operated through desktop personal computers (PCs). Consequently, many EOAE systems can be employed for synchronous telehealth applications including remote computing. Further, remote computing applications for infant hearing assessment seem to have at least three advantages over asynchronous applications. For example, when hearing screenings cannot be accomplished face-to-face, a hearing health care professional could conduct hearing screening from another location. Also, once personnel are trained to conduct infant hearing assessment in underserved area, these individuals can be mentored and supervised by a hearing health care professional in real time while
testing clients. Remote computing also allows observation at distant centers for quality control purposes to achieve appropriate referral rates deterring referrals with excessive false positives.

Finally, diagnostic hearing assessment can be accomplished by hearing health care professionals using remote computing technology. This consideration is important as research indicates that infants with hearing loss require appropriate amplification and aural habilitation before reaching six months of age. Even under ordinary circumstances it can be difficult to conduct follow-up screening, comprehensive hearing assessment and a hearing aid fitting in this time frame unless the infant is precisely managed. In comparison, an infant in an isolated community requiring services at distant medical centers may ultimately suffer from the lack of continuity of care resulting in untimely intervention. Hearing assessment completed remotely by a competent hearing health care professional could serve to reduce the lack of continuity of care and hasten the diagnostic and hearing aid fitting process if needed.

A few papers have been published concerning telehealth and EOAEs in pediatric populations. The first which paper discussed pediatric applications of telehealth and otoacoustic emissions, was by Krumm, Ribera and Schmiedge (2005). This paper provided rationale, models and pilot data supporting the use of telehealth technology with infant hearing screening programs. Additionally, described some of the issues associated with creating a telehealth service including establishing connectivity at the clinic site, use of a VPN to provide patient privacy, and the need to work collaboratively with computer network personnel who do not necessarily share an enthusiasm for telehealth procedures.

In 2008, Krumm, Huffman, Dick and Klich described a study in which they used
remote computing technology to record DPOAEs and automated auditory brainstem audiometry response (AABR) data with infants. Specifically, 30 infants ranging in age from 11–45 days (with an average age of 16 days) were seen for this study. Subjects recruited for this study did not pass prior DPOAEs screening at birth and were being seen for re-screening at their regional medical hospital.

The Biologic ABAER system (Natus, San Carlos, California, USA) was used to conduct all automated ABR (AABR) and DPOAE measurements. The ABAER system was interfaced to a computer and interactive video system in the same manner described previously Krumm et al. (2007). This system was interfaced to a personal computer (PC) running the Windows 2000 operating system and connected to a LAN at the subjects’ site. A second PC was utilized by the audiologist conducting telehealth measurements 200 Km away from the subjects. PCs at both sites were configured with a VCON Vigo desktop videoconferencing system and vPoint software which was used for remote computing applications. Consequently, the audiologist conducting synchronous testing could control both DPOAE and ABR applications at the subject site using the Internet and a broadband connection. A screen capture of a remote session utilizing remote computing technology to measure DPOAEs in a young subject is found in Figure 5. A virtual private network (VPN) connection was provided by the hospital at which the infant hearing re-screening was conducted to protect subject data transmission over the Internet. In addition, immittance and video-otoscopy images were sent from the subject site after being scanned into a computer system to simulate a complete infant telehealth hearing screening service.

Data analysis of this study indicated that DPOAE and AABR screening results
were essentially equal when telehealth and face-to-face trials were compared. Figure 6 displays DPOAE representative results obtained in this study by telehealth and face-to-face methods.

As might be expected, most of the subjects passed the follow-up rescreening in this study. However, some subjects were judged to need further referral. Specifically, one infant was referred on the basis of both DPOAE and AABR screening. Two other infants were referred by the AABR screening, probably as a result of excessive movement, but passed DPOAE screening. Hence, 29/30 infants passed DPOAE screening and 27/30 infants passed AABR screening in this study. Therefore, this study displayed some promise of providing ABR and DPOAE hearing screenings by remote computing to infants over the Internet.
A rating scale was administered to the parents immediately following all infant hearing screenings to assess their satisfaction with telehealth services. One parent of each infant was provided a rating scale to complete. Twenty-six of thirty parents completed the rating scale. Four surveys were not answered as one parent was erroneously not offered a rating scale, and three declined to answer the rating scale. The parents ages ranged from 20-34 years of age and respondents were mostly female (female n=19; male n=7). Parents rated telehealth screening results as excellent (n=22), very good (n=3), or acceptable (n=1). Concerning privacy of infant testing over the Internet, five parents were unsure about privacy, while others were a little concerned (n=8) or not concerned (n=13) about privacy. Although there seemed to be some parental ambivalence about privacy of screening results, all but one parent (n=25) indicated they would permit further telehealth infant hearing screenings.

Figure 6. A comparison of infant DPOAEs recording obtained by telehealth technology (left) and face-to-face by a clinician (right).
Although the outcome of this study was generally positive, it should be recognized there were a number of limiting factors to this study. First of all, the small n size of this study means that comparatively few infants with hearing loss were identified. Consequently, further studies are needed to determine the validity of the telehealth system described in this study on the basis of sensitivity and specificity measurements. No such data has been published in a juried source at this time.

In addition, this study was conducted with one audiologist on-site to provide face-to-face assessments and a second audiologist provided telehealth services at a distance. The fact that testing face-to-face and via telehealth was done by audiologists probably resulted in the high agreement between the telehealth and face-to-face conditions describe in this study. Obviously, assistants at distant sites must apply EOAE probes, ear phones and electrodes to newborns or infants when actual hearing screenings are conducted by telehealth. Also, assistants must be trained to adjust malfunctioning or improperly fitting screening probes, electrodes or earphones during hearing screenings. So, further investigation examining the use of a trained assistant is necessary in future audiology telehealth studies. Again, no such data has been reported in a juried source.

Fortunately, the equipment used in this study provides the capacity to monitor AABR electrode application and DPOAE ear probe placements online when conducting remote computing sessions. Therefore, clinicians can identify and inform screening assistants to correct mechanical problems when infant hearing screenings are provided.

There was one notable problem in this study concerning connectivity. Although Internet connections between subject site and investigator site normally exceeded 384
Kilobits per second (Kbs), on two occasions the bandwidth was compromised by Internet congestion resulting in the loss of interactive video between sites. Even so, remote computing measurement could be continued and hearing screening results were successfully recorded using bandwidth below 100 Kbs. It is interesting that the parents did not respond negatively to the lack of interactive video other than indicating that the testing seemed slow.

Results and conclusions. Although preliminary telehealth results are encouraging for infant hearing screening, additional investigation with telehealth procedures is needed to validate synchronous procedures with greater numbers of infants exhibiting hearing loss. The federal government in the United States has funded several telehealth projects for infant hearing screening and assessment. However, the results of these studies have not appeared in scientific journals.

In addition to synchronous research, asynchronous and hybrid telehealth models should also be studied for EDHI screening, diagnostic and intervention services in rural communities. For example, in Northern Ohio (USA) one audiologist used asynchronous technology to measure DPOAEs with preschool children during hearing screenings (B. Whitford, personal communication, September 4, 2008). Further, clinicians providing direct EDHI services may consider the need to implement different newborn hearing screening protocols proposed in the literature to reduce false positives and follow-up visits (Gravel, White & Johnson et al., 2005; Lieu, Karzon, & Mange, 2005). These protocols include auditory brainstem response (ABR) testing at the time when newborns fail initial screenings; simultaneous use of both AABR and EOAE screenings at newborn screenings; and detecting middle ear disorders through high frequency tympanometry.
measurements. An audiologist could employ telehealth technology to provide some of these services.

Remote computing might also prove valuable as a means to provide ongoing instruction to hearing screening assistants established in rural areas. Specifically, clinicians can mentor and monitor assistants using remote computing applications while viewing newborn hearing screenings in real time. These services would be dispensed with the goal to enhance personnel expertise for newborn hearing screenings.

For clinicians contemplating telehealth applications, a few issues need to be reviewed. First of all, additional licensure or other clinician certification, may be needed to provide services in different regions and certainly countries. Also, informing the proper licensing authorities that telehealth services are being considered is sensible even if the clinician license permits such services. Reimbursement for telehealth services may be unclear so funding sources must be clearly identified before telehealth services are initiated. Also, while it has been the experience of the author that most computerized audiology systems work well for remote computing applications, clinicians must prototype prospective computerized audiology systems for the remote computing and asynchronous applications to be assured that the telehealth technology will work as desired.

Remote computing software is abundant. However, web-based conferencing software may be faster and just as cost effective as PC based video-conferencing software. Programs such as Teamviewer, Skype and DimDim may be used to provide low cost means to remote computing services but privacy must be assured through encryption or through a virtual private network (VPN). Teamviewer offers good
encryption capabilities. Skype has offered encryption under paid plans. So, video/data encryption or the use of a VPN must be carefully considered. Finally, the author would also advise clinicians to conduct telehealth services at distant sites first in which there is enthusiastic support. Even though telehealth is powerful, it is of no value if key personnel at the distant clinical site do not support new service methods.

In conclusion, while telehealth technology seems reasonable to use for screening and diagnostic services, the author recommends cautious validation and program review. Questionnaires should be provided to consumers who are served through telehealth services. Also, planning committees consisting of consumers, administrators and clinicians should be formed to assure proper procedures are developed for EDHI telehealth services. Following the establishment of these mechanisms, clinicians could implement substantial telehealth strategies to bolster rural community services for parents and their hearing impaired infants.

References


