e-Health technologies for adult hearing screening

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Abstract

The development of hearing diagnosis methods and hearing screening methods are not isolated phenomena: they are intimately related to changes in the cultural background and to advances in fields of medicine and engineering. In the recent years, there has been a rapid evolution in the development of fast, easy and reliable techniques for low-cost hearing screening initiatives. Since adults and elderly people typically experience a reduced hearing ability in challenging listening situations [e.g., in background noise, in reverberation, or with competing speech (Pichora-Fuller & Souza, 2003)], these newly developed screening tests mainly rely on the recognition of speech stimuli in noise, so that the real experienced listening difficulties can be effectively targeted (Killion & Niquette, 2000). New tests based on the recognition of speech in noise are being developed on portable, battery-operated devices (see, for example, Paglialonga *et al.*, 2011), or distributed diffusely using information and communication technologies. The evolutions of e-Health and telemedicine have shifted focus from patients coming to the hearing clinic for hearing health evaluation towards the possibility of evaluating the hearing status remotely at home. So far, two ways of distributing the hearing test have primarily been used: ordinary telephone networks (excluding mobile networks) and the internet. When using the telephone network for hearing screening, the predominantly test is a speech-in-noise test often referred to as the digit triplet test where the subjects hearing status is evaluated as the speech-to-noise threshold for spoken digits. This test is today available in some ten countries in Europe, North America and Australia. The use of internet as testing platform allows several different types of hearing assessment tests such as questionnaires, different types of speech in noise tests, temporal gap detection, sound localization (minimum audible angle), and spectral (un)masking tests. Also, the use of the internet allows audiovisual presentations as well as visual interaction and cues in the tests for a more ecological approach. Even if several new and novel approaches for hearing assessment using the internet are surfacing, the validated tests are based on questionnaires or speech-in-noise. Although the internet allows for a broader flora of pure auditory and audiovisual tests for hearing health assessment, calibration problems such as timing uncertainty, output levels and modes of presentation (speakers or earphones) limits the usability at present.

Introduction

One goal of the EU-project AHEAD-III (EU project AHEAD III, 2008-2011), was to investigate the feasibility of newly proposed hearing screening technologies for adults and to evaluate preliminary results from such methods if available. One important question arises at the beginning of such task: what is a new technology? As will be seen later, there are not many methods that are truly new, but mostly used in a different setting than traditionally. To simplify the issue, new technologies are here defined as non-classical screening technologies and are exemplified by four different frameworks for adult hearing screening: i) Genetic testing, ii) telephone based screening, iii) internet based screening, and iv) consumer electronic based screening (e.g. smartphones).

Another important question to be addressed is the target of the screening. When considering the ICF model for hearing (World Health Organization, 2001), the screening should be for hearing disability. However, not all technologies target the disability but rather hearing impairment. Also, since a hearing screening test in itself is not interesting but should be accompanied by an intervention, the when and where of testing must be considered. When considering newborn hearing screening, the obvious timing is close to birth when several other tests of the infant are performed and usually in a clinical setting. For the adult, time and place are not equally obvious. If the screening is administered too late, the subject has already been disabled for some time without proper intervention. On the other hand, a too early screening can have negative effects if the result is that the subject has a good hearing and do not require an intervention. Such testing is cost

inefficient and the information can be used many years afterwards as a reassurance of good hearing and thereby postpone help seeking when actually needed. Consequently, timing is essential and the chosen method depends on the age group and place of testing, for example in the clinic, in public, or perhaps distributed over the internet.

Available Methods

When it comes to different methodologies available to test the hearing functions they all have advantages and disadvantages. Tonal detection, which is widely used for assessment of the hearing function, requires calibration of the levels and frequencies used. Questionnaires are used to assess subjective hearing status but may be less effective to identify early stages of hearing disease as can be detected by other techniques. More objective types of tests as otoacoustic emissions or electrophysiology based tests may be too costly and cumbersome, and may not be appropriate for screening of an adult population. Several screening tests devised are based on speech material as base. Although speech probes communication abilities and is a good way to assess communication problems, the tests are often language specific and it is not always possible to compare results of similar speech tests in different languages. In terms of distributed tests, where the test subject can easily access the test without the need of being at a specific place, the digit triplet test (DTT, speech test) (Smits *et al.*, 2004) and the screening versions of the Hearing Handicap Inventory for the Elderly questionnaire (HHIE-S) (Ventry and Weinstein, 1983) are the most widely used tests that are validated. Both tests can be implemented on the internet and by telephone, but, questionnaires are seldom implemented in a telephone setting.

Genetic screening

The aetiology of age-related hearing loss (ARHL) is multifactorial including both environmental and genetic factors (van Eyken *et al.*, 2007). Although some correlation between genes and ARHL have been found, this line of research is still in the beginning and today, based on our current knowledge, no genetic test for ARHL is available. This area show potential and it is clear that genetics have influence on ARHL; however, it's usability in screening for ARHL is unclear.

Digit triplet test

The digit triplets tests (DTT) determine the speech intelligibility in speech shaped noise using combinations of three digits per stimulus (Smits *et al.*, 2004). It was first implemented for the telephone in the Netherlands but has through the EU project HearCom (HEARCOM, 2004) been developed in several other European languages. The DTT is implemented in both telephone and on internet. The benefits of using a normal telephone is that most people have access to a telephone and the test is easily accessible (dial a number). A general drawback of the DTT is that it is limited to numbers between zero and nine that should be monosyllabic. Consequently, the included digits differ between languages and in some languages multisyllabic digits have to be included. Moreover, the telephone system limits the frequency bandwidth and the amplitude resolution and responding using the keypad can be difficult in handheld devices. Yet another drawback of the DTT is that it currently cannot be administered using mobile phones.

Using the internet to distribute the test overcome some of these problems but imposes some new ones: the elderly population that is targeted for hearing screening has the lowest internet penetration and for auditory tests on the computer the user must be able to control the sound card and the earphones or speakers. Moreover, in a study comparing hearing screening methods in the UK, Germany, and the Netherlands using a postal-based questionnaire, it was found that questionnaires was preferred over the internet that was preferred over telephone based screening (Koopman *et al.*, 2008).

The DTT is a speech-in-noise test where the aim is to reach 50% intelligibility. The signal-to-noise ratio (SNR) at the 50% thresholds varies between languages and ranges typically between -7 to -4 dB for normal hearing subjects (Wagener, 2009). The test uses an adaptive algorithm to reach the threshold and takes about 3 minutes (Wagener, 2009).

The sensitivity and specificity of DTT has been determined for the Dutch version and a modified English version of the test. In the Dutch test, the correlation between the DTT using headphones and $PTA_{0.5, 1, 2}$ was 0.771 and $PTA_{0.5, 1, 2, 4}$ was 0.821 (Smits and Houtgast, 2005). When the same test was administered by telephone the correlations became 0.732 for $PTA_{0.5, 1, 2}$ and 0.770 for $PTA_{0.5, 1, 2, 4}$. Using a -4 dB SNR dividing line between normal hearing and hearing impaired subjects led to a sensitivity of 0.91 and a specificity of 0.93 (Smits and Houtgast, 2005). In a slightly modified version of the DTT National Acoustics Laboratory reports a correlation between the DTT and $PTA_{0.5\ 1, 2, 4}$ of 0.77 (N=75) (National Acoustic Laboratories, 2007).

Questionnaires

Questionnaires are easy to implement on the internet and several verified tests for hearing screening exists. The HHIE-S consists of 10 items from the original 25 items HHIE (Ventry and Weinstein, 1982) and is often used as a screening questionnaire for problems with hearing and communication (Ventry and Weinstein, 1983). The questions are scored according to three alternatives: yes (4 points), sometimes (2 points), and no (0 points) (total score ranges between 0 and 40 points). ASHA recommend fail-criteria of 10 points or more. Using this criterion, the sensitivity ranges 0.63 to 0.80 and the specificity ranges 0.67 to 0.75 when related to failure of hearing a 40 dB HL tone at 1 or 2 kHz in either ear (Yueh *et al.*, 2003).

Another questionnaire that can be used for hearing screening is the Self Assessment of Communication (SAC) questionnaire (Schow and Nerbonne, 1982). It also contains 10 questions where the answers are given on a 5 point scale yielding a total score between 10 (no hearing problem) to 50 (severe hearing problem). Correlation between the SAC and pure tone average is reported to be 0.78 (Schow, 1995). Even single question questionnaires, such as "Do you have any difficult with your hearing?" (Stephens *et al.*, 1990) show relatively high sensitivity and specificity. When evaluating such questions in elderly population, the sensitivity ranged 0.71 to 0.93 and the specificity ranged 0.56 to 0.87 (Valete-Rosalino and Rozenfeld, 2005).

Other internet-based screening tests

Speech-in-noise tests of other types can also be used to screen for hearing impairment on the internet. Typically, such tests uses identification of keywords in a sentence and the task is to identify if an object (in the form of a picture) is present or not (two-way forced choice alternative) or identify one object among several items that was present in the sentence. One example of the latter has been implemented at the hard of hearing website in Sweden using the closed set of Hagerman sentences (Hörselbron, 2011). However, no data of the sensitivity and specificity of such tests or how they correlate to PTAs have been provided in the literature. Another screening test available is the minimum audible angle test (HEARCOM, 2004). Hearing screening test that are based on gap detection and binaural hearing abilities have also been administered on the internet.

Smartphones

A recent development is the use of smartphones (e.g. iPhone and Android phones), which are integrated communication devices with the ability to program and control the audio output. Using this ability to control the audio output, so called applets (small programs) can be installed that tests the hearing ability. However, no such applets have been verified in terms of test-retest reliability or correlation with other auditory or communication tests, such as the audiogram.

Discussion

It is not unambiguous how to define new technologies for adult hearing screening. Here, it is defined it as non-classical screening methods. Even so, in this presentation it is only genetic screening that can claim to be completely new, the other screening technologies reviewed use conventional assessment techniques (primarily speech-in-noise thresholds or questionnaires) but is administered in a new way: by telephone, the internet, or as applications in smartphones.

The use of internet provides a fast way to reach many people, which makes it very usable for adult hearing screening. This means that one may reach many presumptive persons with hearing problems cost-effectively. However, the use of the internet poses several difficulties as well. One such problem is validation of the hearing tests. Today, most hearing screening tests available on the internet are not validated and it is not always obvious for the person taking the test. Unless there is some sort of validation, it is impossible to interpret the outcome of the test. There are at least two problems: i) if the test is not sensitive enough people that would benefit from a hearing intervention do not receive the correct information about their hearing status, and ii) if the test is not specific enough, people will seek help that they do not benefit from and the confidence for online hearing tests is reduced. Consequently, to reduce the problem of non-validated online hearing tests, adult hearing screening could be conducted in a controlled setting like in the clinic. However, hopefully official organizations will provide free online hearing tests that are validated, as the DTT or questionnaires as the HHIE-S, and hard of hearing organizations and hearing healthcare companies (including the hearing aid industry) would use these test instead of providing own non-validated tests. It should also be understood that a hearing screening should be accomplished by a hearing intervention. Therefore, the choice of screening technology should be in accordance with the intervention and specific screening program. As a consequence, one cannot simply conclude a technology as best suited for adult hearing screening but, for most adult hearing screening programs, different technologies could be appropriate.

Conclusions

It has been shown that ordinary telephone, the internet, and newly introduced smartphones provides for screening of hearing status at home. There are several hearing tests implemented on the internet; however, only a few are verified in terms of sensitivity and specificity. Beside well documented questionnaires as the HHIE-S, the DTT using a signal-in-noise rationale is the most documented telephone/internet based test. Smartphone applets are the latest trend in platforms for hearing screening.

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