eHealth for Hearing – New Views and Apps Practicalities

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Abstract

Background: We are observing a silent and disrupting revolution in the hearing health care practice due to the pervasive use of eHealth methods and technologies, in particular mobile apps. This situation is very new, e.g., in the novel interactions and relationship between actors, in the implicit knowledge relevant to actors, and in the acquisition and comprehension of health messages and fragmented, e.g., in knowledge, standardization, regulation, and in methods for quality evaluation, so here we propose a new paradigm.
Objectives: We want to contribute to the definition of the boundaries and rules of the new 'eHealth4Hearing' paradigm.
Methods: Starting from the needs perceived by people with hearing disabilities, we formulated a new 'eHealth4Hearing' paradigm and gave practical examples on its application.
Results: The 'eHealth4Hearing' paradigm is delivering a new patient-centered model where people have (1) tools for at-home checking of hearing status to monitor or to detect early hearing disabilities; (2) tools to acquire meaningful, accurate and personalized information on how their hearing condition may affect their lives and to simulate how different rehabilitation solutions will work for them; (3) tools for self fitting/control of hearing systems; (4) personalized solutions for sound enhancement through smartphones for people that do not require traditional hearing aids; (5) at-home interactive rehabilitation programs adapting to their speech and communication skills.
Conclusions: Researches have to be devoted to further boost the potential of 'eHealth4Hearing' and must address issues concerning safety, privacy, legal regulations, reliability and quality of the apps.

Keywords

eHealth, hearing health care service, paradigm shift, mHealth, patient-centered delivery model

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1 Introduction

The word "e-Health" portrays various meanings to its readers from the general public, to the professionals, probably up to every of its stakeholders; among them are a high speed of communication, joined with a potentially high selectivity of the specifically delivered message, and the release of the former and rigid separation of some sensory channels (typically the visual and the auditory ones).

"Hearing" is a clinical domain where the interactions between the patient and their caregivers frequently are unsatisfactory on both sides, often just because of the people's ignorance of hearing basics. Additional elements of unsatisfaction are the subject's usually late understanding of their hearing status, the absence of easily accessible, reliable, and self-administrable hearing tests, and the ignorance of the growing time and efforts and difficulties requested by any rehabilitating hearing action even if it includes the adoption of costly hearing aids (HAs) when undertaken late in respect to the hearing loss process. Unsatisfaction occurs even if such hearing loss is perceived to be limited to specific and avoidable environments, such as listening to superimposed discussions at a meeting, watching television, answering the phone, etc. The patient must not simply decide to avoid these specific situations, as this decision may well be the beginning of a serious increases of their hearing loss.

Can we describe the practical differences between the historically intended hearing care environment and the envisaged 'eHealth4Hearing' one? Could the 'eHealth4Hearing' environment help improve some of the several keywords-for-hope that emerged, such as patient-

centeredness, patient empowerment, patient-caregiver relations, and others?

This paper is meant to give an answer to:

1. what could be the envisaged new 'eHealth4Hearing' paradigm;
2. how the 'eHealth4Hearing' paradigm may help patient-centredness, patient empowerment, and patient-caregiver relationships; and
3. what the main differences are between the traditional health care practice and services for the hard of hearing and those delivered through the new 'eHealth4Hearing' paradigm.

We will give practical examples of the implementation of the 'eHealth4Hearing' paradigm by reviewing the best-practices in the services provided by the apps in the field of hearing care.

The paper is organized as follows: we will first describe in Section 2 the main causes of hearing disability, the target groups we focus on, their perceived needs and the traditional healthcare and rehabilitation paths. At the beginning of Section 3, we will describe the new 'eHealth4Hearing' paradigm and its structure, starting with some envisaged scenarios (the 'whishing cases'). In Section 3 we will also give some highlights on the current opinions of the target groups and hearing care professionals on the new perspectives brought forward by the ICT for health and on the new paradigm in particular. In Section 3.1 we will review some of the new 'eHealth4Hearing' care services in practice. We will focus on the apps as examples of the possible strategies that can be adopted to implement the new services that will address the needs of the target groups we considered. In that section, in particular, we will review what the current best practices in the apps of the hearing care field are and will comment on how they address the needs of the specific target group and how they help patient-centredness, patient empowerment, and patient-caregiver relations. Finally, in Section 4 we will draw the conclusions and illustrate the future directions.

For sake of clarity, Appendix 1 shows the main components, i.e., the target groups, perceived needs, health care and rehabilitation paths, and the new 'eHealth4Hearing'services, that have been considered in our study, summarizing a brief description of their main characteristics. The detailed descriptions are given in the following Sections.

2 What We Inherited about the Current Needs

Hearing impairment (HI) is one of the most frequent sensory impairments, which affects newborns, children, adults, and the elderly. As of 2012, about 10% of adults under 65 years and 36% of those older than 65 years in Europe had a disabling hearing loss (HL) [1]. HL can be due to different etiologies, ranging from congenital causes, ear infections, assumption of ototoxic drugs (such as in the case of people treated with chemotherapy drugs), to noise exposure (affecting 16% of the adult population worldwide [2]) and the aging of the auditory system. Depending on age, etiology and severity of the impairment, people require different clinical paths and different care solutions. For example, solutions for people with severe-to-profound HL include HAs, cochlear implants, assistive tools, and sign language: in this last case, it has been estimated that around 500,000 people across the EU use sign language as the first-choice communication mean [1].

The psychosocial effects of HI can come slowly, but they can undoubtedly come to be evident and dangerous, with a detrimental impact upon an individual's quality of life. Effects include loneliness, social isolation, exclusion, stigma and low self-esteem, denial, difficulties in particular environments, memory loss, prejudice and abuse, and employment difficulties. Family relationships, education, cognitive skills and intimate relationships may also be affected [3]. Most of the effects are direct consequences of the problems experienced in interacting with other people and the individual's environment and can reduce a person's physical, functional, emotional and social well-being [4]. There is also a significant comorbidity in older adults with HL, for example, balance disorders and tinnitus [5], higher probability for depression [6] and higher risk of dementia [7]. Unmanaged hearing problems are also associated with poorer self-management of longterm conditions [8].

2.1 The target groups

As illustrated in Appendix 1, we considered four "functional" target groups of people, consisting of subjects with a HL, as described above, and including also subjects with tinnitus and speech, language and communication diseases. The target groups were defined according to the types of services that are required to manage their disability and not to the type (or etiology) of their impairment. As a matter of fact, it may happen that the same service helps people with different types of impairment. The four "functional" target groups are:

1. people needing/wishing to perform self-hearing assessment/monitoring hearing functionality;
2. people needing amplification;
3. people needing hearing and communication rehabilitation;
4. people needing assistive tools, including those hard of hearing using sign language.

2.2 The perceived needs

Figure 1 summarizes the five groups of the most frequently observed needs perceived by the target groups

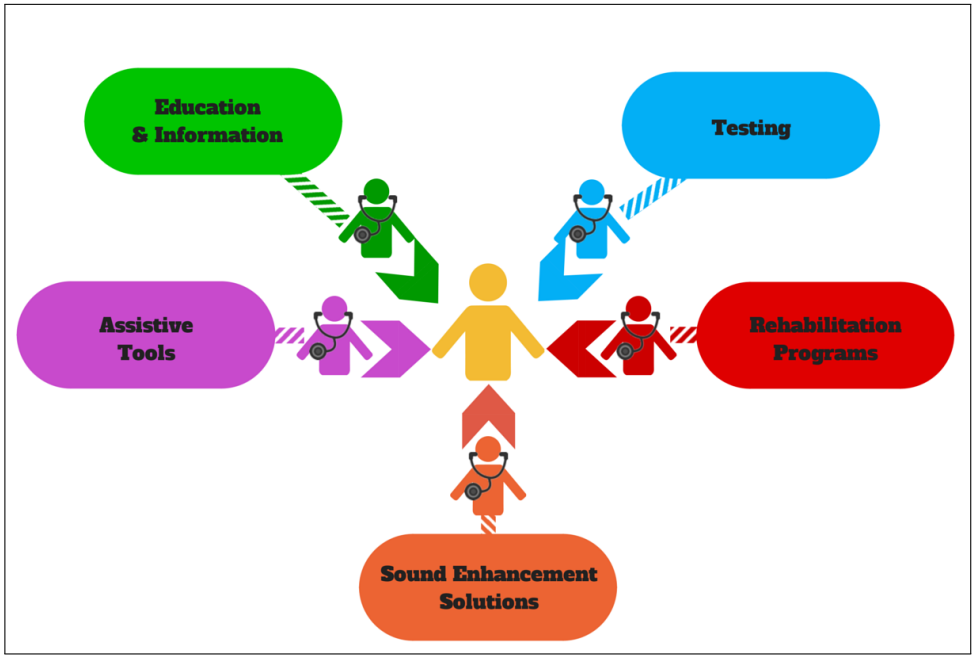

Figure 1: Traditional doctor-centric model. The needs perceived by people with hearing disabilities and the role of hearing care professionals: solutions to people's needs are conventionally delivered mostly through hearing care professionals.

considered so far (see also Appendix 1). Below is their description.

Education and Information Towards Empowered User Profiles

These are the needs perceived by all the four target groups described above (see also Appendix 1), since a better knowledge and education about their own or their relatives' hearing impairment could help the patients and their caregivers to be an active part of the process for the management of their health issues [9]. The most important needs are:

- Timely, accessible, meaningful, reliable and properly tuned information on hearing disorders and their impact on health, quality of life, communication skills and social inclusion (see, e.g. [9]).
- Accessible information on what options are available to treat hearing disability and which benefits each of these options can give to the specific hearing problem of the subject. For example, parents of hearing impaired children are required to make choices about the management of their child's hearing and therefore they need accessible information on outcomes, available technology for hearing amplification, communication options, education, and rehabilitation (see, e.g. [10]).

Sensitive Testing Towards Life-Long

These needs are important for the 1st target group and can be summarized as follows:

- Tools for measuring and monitoring hearing function and for detecting early hearing impairment to be used at home (see, e.g., [11]).

Sound Enhancement Solutions Towards Flexibility and Multi-sensorial Integrations

These are the needs perceived by 2nd target group:

- Straightforward and flexible tools to adjust and tailor in real time the listening settings of hearing systems, with limited intervention of a hearing care professional or technician or of cumbersome hardware (see, e.g., [12]). Availability of technological solutions for HA self-fitting or self-adjustment is one of the top five key factors that would increase the likelihood that an unaided patient will seek a HA [13].
- Quick, easy and cheap solutions for personal sound amplification other than traditional amplification solutions (e.g., HAs) (see, e.g. [14]).

Rehabilitation Programs Towards Best Fitting and Flexibility

These are the needs perceived by the 3rd target group:

- Easy and meaningful tools to perform home-based hearing rehabilitation that interactively adapt to the listening and communication skills of the subject [15]. The flexibility of scheduling, possibility to perform rehabilitation at home, and ease of rehabilitation procedure are factors that most influenced hearing rehabilitation outcomes in adults [16].

Assistive Tools

These are the needs important for the 4th target group:

- Easy, cheap, flexible and reliable solutions to assist hard of hearing and deaf people to live more independently by using telecommunication devices [17], reacting to sound in the environment [18], and learning and using sign language.

Patients and healthcare professionals believe that traditional care models are somewhat inadequate to satisfy their expectations and that digital technologies are the key-factors for creating new care models [19]. About 50% of healthcare professionals participating in the survey in [19] said that digital visits could substitute more than 10% of in-office patient visits; about 42% of them said that they are 'at least somewhat comfortable' relying on self-test results to prescribe medication; and nearly 30% were in favor to promote self-management of chronic disease and would be willing to prescribe health apps. Patients also expressed their willingness to communicate with their caregivers online [19]. Similar trends/opinions were collected in other surveys, regarding things such as people beliefs and preferences on digital health care [20], the biggest qualities and needs perceived by consumers of health apps [21], and surveys conducted among healthcare providers [22].

2.3 The traditional healthcare and rehabilitation paths

We are witnessing a radical change in the way hearing healthcare can be delivered, the most evident being the trend towards the so-called patient-centered care model [15, 23]. Individuals are now provided with novel services and tools that show great promise to enhance the benefit of their healthcare and rehabilitation paths. Conventionally, before the advent of mobile solutions, these paths relied heavily upon frequent face-to-face appointments, large use of clinical equipment (for assessment and rehabilitation), and ample utilization of paper-based material. Appendix 1 summarizes the main traditional healthcare and rehabilitation paths for each of the four target groups.

1. People who need hearing screening, assessment and monitoring typically need to search for the nearest or most reliable clinical center or HA provider and ask for a hearing test. Moreover, people who need to monitor their hearing functionality frequently (e.g., because they are exposed to ototoxic agents or noise) should go through regular, time-consuming checks. This sometimes creates barriers that prevent people from checking their hearing as frequently and as accurately as they should.

2. People requiring hearing systems typically need to go through periodic and time-consuming fitting sessions with their audiologist or HA provider to adjust their amplification settings. The time and effort needed to reach a satisfying amplification may lead many people to neglect these appointments and greatly limits the benefit of the hearing system they wear.

3. People requiring hearing and communication rehabilitation, or speech and language training, typically need very frequent rehabilitation appointments with their therapist or speech and language pathologist and not all people can stand such a long and difficult process. Moreover, when the patient is a young child, the required time and commitment of parents or relatives can be huge and sometimes families are not able to afford such an effort potentially hindering the communication and learning development of children.

4. Deaf and hard of hearing people, who might benefit from assistive tools, typically find it difficult to communicate over the phone, or to live independently. Conventionally, they are used to relying on speakers or headphones to watch TV or listen to the radio or talk on the telephone, and sometimes they have no solutions to deal with everyday sounds that they cannot hear. It is clear that the use of smartphone-based, integrated solutions can be a simple, and ubiquitous, way to provide these people with tools to assist their communication and daily living.

3 'eHealth4Hearing': the New paradigm in the Hearing Health Care Field

"New Paradigm" is an infrequent and engaging expression. However, we decided to use this term because it comes from our perception that the hearing scenario allowed by ICT for health is quite new and better. To identify the reasons of such a perception of relevant novelty, let us think about a few practical cases and how easily they might be implemented by ongoing technologies. Even if the final solutions might still require some years of development, and reasonably they will be implemented one at a time, it is clear how their implementation was obviously impossible before these technologies had become available.

Wishing Case 1 – Could a self-administrable hearing test with the purpose of alert generation to be delivered/taken at home frequently, be considered useful to oncologic patients enrolled in at-risk-of-hearing-losses therapies? We also realize that "self-administrable" is the gateway making "frequently" affordable, as needed by "alert generation" in the attempt to better protect the already suffering patient. A tailored design of the already-available eHealth infrastructure let us believe that this scenario can be real. The practical absence of additional working time for the hearing therapist is a key factor for

making the process accepted also by national healthcare systems which are notoriously sensitive to money saving. The 'Wishing Case 1' is an envisaged scenario related to the first target group, the one of people needing/wishing to perform self-hearing assessment/monitoring (see Appendix 1).

Wishing Case 2 – Could a wider variety of standardized hearing sources, to be added to the historically settled tonal and vocal procedures for taking audiograms, be embedded in the hearing tests, in such a way to refine and add sensitivity and specificity to what is generally intended as audiograms, up to the point of profiling tests useful to specific working environments? Also in this case the positive answer can be trivial. Body auscultation for medical diagnosis, musicians activities, logopedists treatments and other working profiles would obviously appreciate the availability of hearing tests using ad-hoc hearing source collections, that can be taken at a distance, on demand, autonomously, at an only-minimally ICT-infrastructured environment. This 'Wishing Case' illustrates another scenario associated to the target group 1 (see Appendix 1).

Wishing Case 3 – Could a suitably designed but merging of both the hearing and visual human senses deliver services so as to facilitate the complex and uncertain counseling of people who begin to use HAs? Exercises where a same text comes from both a loudspeaker and a video display and these two sensory-sensitive sources are integrated in a training strategy that is easily monitored quantitatively, and seem to be ready for implementation, again by entry-level ICT infrastructures, even by not-so-complex apps. This 'Wishing Case' exemplifies two scenarios: the one of people needing amplification (target group 2, Appendix 1, for issues related to HA counseling) and the other of people needing hearing and communication rehabilitation (target group 3, Appendix 1, for issues related to auditory training).

We might not need to add more cases for beginning to welcome a common framework we name it "paradigm" - where each case is just one of its instantiations. In doing so, we explicitly recognize the truth that, also in the field of hearing loss, a "previous" paradigm already exists, as already effectively visualized in Figure 1. It should be easy to agree on, as it grounds on the generic and implicit hearing knowledge of our times. But the fitting into Figure 1 of each of the wishing-but-at-hand cases described above remains unclear, and relies too much on hopes and imagination.

While putting into practice our attempt towards a better framework, we came to Figure 2, where the "e-Health bus" and what it allows is the grounding element of the "new" paradigm. "Bus" is to be intended as in the computer domain. Its behavior lets each of the connected actors and services to ask to use it, - temporarily, almost entirely and on demand, - for its own communication purposes, such as the message contents and the message addressees [24]. Something like "what to say to whom". Moreover the "bus" allows each communication action to occur in real time in respect to the reaction times of humans - and is permitted at a distance. Also the autonomous self-search of an actor at any data source is a communication action. As the "e-Health bus" is a default ICT infrastructure, the Figure 2 as a whole is true. Nevertheless its truth carries also some difficulties. Research groups who historically settled on only the "previous" paradigm might take time to re-tune themselves so as to dominate all the possible instantiations allowed by the "new" paradigm. For the purposes of this article, we believe we have given sufficient observations supporting the idea that we are in front of a "new paradigm", to which Figure 2 provides a useful visualization.

Through the eHealth Bus, each of the actors can share resources, data, information and services with all the other relevant actors and can have direct access to the available resources and services. This new path potentially leads to a dramatic change both in the roles within the actors and in the way in which patient needs are addressed and solved. Differently from the traditional doctor-centric model (see Figure 1) in which the access to health care services, resources and solutions occurs mostly through the hearing care professional, now in the new 'eHealth4Hearing' care paradigm, patients can have direct access to a wealth of solutions, health services and resources. The new 'eHealth4Hearing' paradigm is centered around the patient, who is encouraged (and sometimes even pushed by the available technology and the input from the society) to take control of her/his own health.

There are several examples that illustrate the positive attitude of hearing care professionals and patients towards eHealth in the hearing care field. For instance, some of the novel ways with which hearing care services are starting to be delivered include: remote auditory examinations [25], self-assessment of hearing sensitivity [26], self-fitting of HAs [27], remote mapping of cochlear implants [28], remote delivery of cognitive-behavioral therapy [29], and remote counselling [30]. A positive attitude towards the 'eHealth4Hearing' concept is seen also in HA manufacturers: some of them are developing systems that, through a web-based platform and an ad hoc interface plug, will help people to self-adjust the HA gain and settings to optimize the comprehension of speech in noise and give an help to HA troubleshooting [31]. All these examples give a clear picture that, although at its beginning, the hearing care model is changing from its traditional configuration, and that hearing care professionals, patients and manufacturers are becoming more and more aware of this change (and are somewhat leading the change).

3.1 The 'eHealth4Hearing' Paradigm in Practice

As a practical exemplification of the 'eHealth4Hearing' paradigm, we will focus on mobile health apps. The number of health apps has more than doubled in the past 2.5

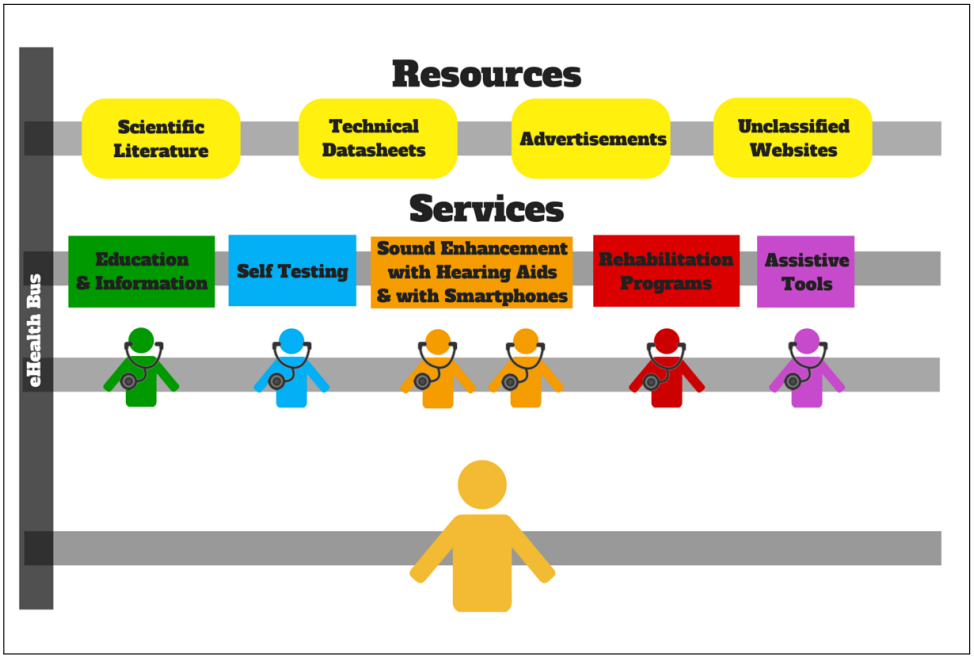

Figure 2: The new 'eHealth4Hearing' paradigm of health care practice: the application of ICT methods and technologies creates a new connecting path the 'eHealth Bus' among the different actors (hearing care professionals, providers, and patients), services, and the available resources. The eHealth Bus changes both the roles within the actors and the way in which patient needs are addressed and solved. The new 'eHealth4Hearing' paradigm is centered to the patient, who is encouraged (and sometimes even pushed by the available technology and the input from the society) to take control of her/his own health.

years, with more than 100,000 apps in Q1 2014 [32]. Current estimates [33] predict that by 2017, half of the 3.4 billion smartphone or tablet users worldwide will use mobile health apps. It is to be reminded, however, that the application of ICT in the hearing health care has been implemented also with web-information platforms on hearing matters, web services for the delivery of hearing tests, and tele-audiology services (see, e.g., [34])).

Apps in the field of hearing healthcare were searched for using the following keywords: hearing, audiology, audio, auditory, speech, language, tinnitus, hearing loss, HA, hearing system, cochlear implant, auditory training, hearing rehabilitation, assistive technology/tool/device.

Apps were pooled into five group of services, as illustrated in Figure 3, following the same classification schema used for describing the needs perceived by the target groups (Figure 2 and Appendix 1). Figure 3 also gives a short description of the main features of each group of services. Below is the description of each service, of its best practice implementation and the target groups that it addresses. Appendix 2 shows the number of apps we downloaded for each service and summarizes the relevant/innovative features of a number of apps that were selected as the representative ones.

Education and Information Services

These services address the needs perceived by all four target groups to easily retrieve specific educational material on hearing conditions (see, Appendix 2). Several apps in this group of services are a kind of 3D interactive and animated atlases describing the anatomical structures of the ear and use short educational videos; others explain main ear diseases, perform simulations allowing the users to playback pre-recorded common sounds or their own voice through different HL configurations; others explain in plain words the meaning of audiometric test results, and help in preventing hearing impairment by monitoring in real time the level of potentially harmful sounds. These apps contribute to enhance effective communication of health related information regardless of the level of health literacy and are likely to improve the engagement of people with their health concerns.

Self Testing

These services address the needs of the 2nd target group. They might assume particular relevance for older people and those with early signs of HL who may be reluctant to ask for an assessment by hearing care professionals. Self-testing (see Appendix 2) can be performed at home through smartphones or tablets with no requirement of particular settings (i.e., there is no need to perform the test in sound-proof booths). In most cases, tests require the use of general purpose headphones or earphones; otherwise, they require ad hoc headphones which can be purchased from the app developer. The test procedure is quick (usually it takes less than five minutes) and totally automated for what concerns both the delivery of the audio test signals and the storage and interpretation of test

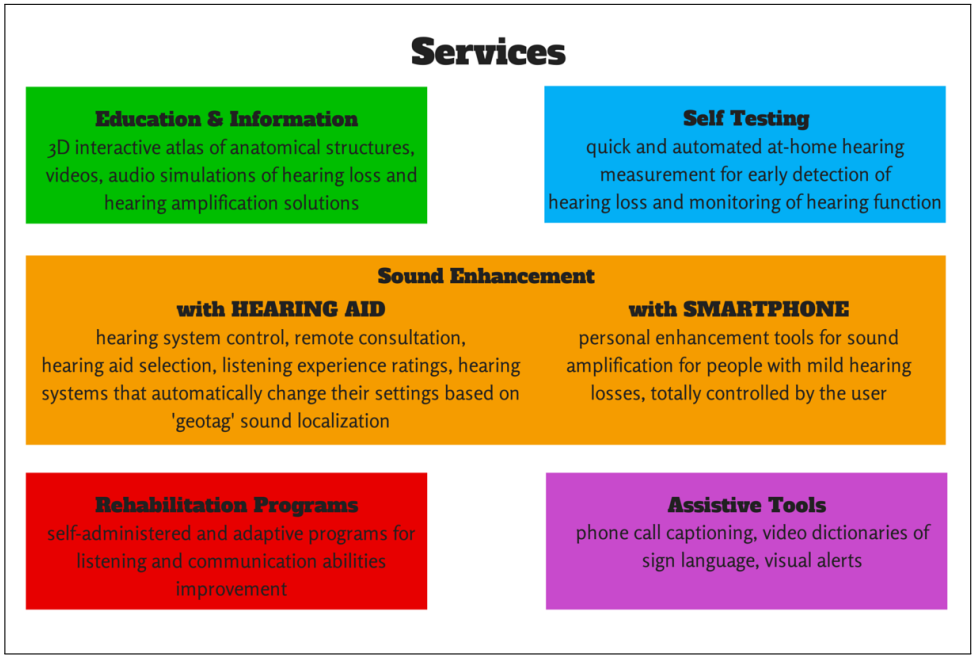

Figure 3: The new groups of services delivered in the 'eHealth4Hearing' paradigm through mobile apps.

outcomes. The tests score hearing functionality by measuring the audibility of pure tones or other audio signals, such as syllables or words embedded in noise. Some apps include also a way to measure the level of the background noise. Although there are still a lot of critical aspects that must be addressed, such as the reliability of the measures (due to, for example, the use of earphones of bad acoustic quality or that are not calibrated, or the administration of the test in rooms that are too noisy, etc.), these apps could promote early identification of hearing diseases (by making periodical hearing tests easy) and could also improve patient empowerment (by giving a clear and straightforward measure of HL).

Sound Enhancement Solutions

These services include sound enhancement solutions implemented with (i) smartphones and with (ii) HAs (see Appendix 2). Both solutions address the needs of the 2nd target group.

- Smartphone solutions. Apps in this group perform real time personalized amplification of voice and sounds by using the smartphone amplification and by delivering the amplified sound through the smartphone earphones. These apps are for subjects with mild HL that do not require classical HA amplification and are intended for occasional use, typically to enhance speech in noisy situations (such as in crowded spaces). Differently from standard HAs, which can be costly and are dispensed only by a hearing care professional after a hearing evaluation, these apps are available on the shelf. The most basic version of these apps applies a mere amplification of the volume of the incoming sounds; others allow the users either to choose one among a number of pre-set amplification programs or to customize the amplification profile to best fit their HL. Even in the basic configuration, these apps immediately provide some kind of amplification even to those subjects for whom traditional HAs would not be a feasible solution (being their HL of mild degree), thus potentially improving their quality of life.

- HA solutions.

A Hearing system control and maintenance: most HA manufacturers are producing hearing systems that can be remotely controlled (e.g., control of volume, listening program, sound settings, and direct streaming of phone calls) through dedicated mobile apps. In some more advanced apps it is also possible to tag a location and associate to that location a personalized sound setting that has been saved in the memory of the HA. These advanced apps can also record, play back and email audio streams received through the smart phone audio input channel and allow, finally, to use the smart phone as a microphone to stream conversation directly to the HA. All these apps allow people to suit their hearing systems on their sound preferences in real time, precisely, easily and with no extra hardware required.

B Remote consultation and individual engagement services: these apps are intended for counselling patients on their hearing status. They engage patients to become an active participant in the HA selection process. A number of apps allow capturing and rating patient personal listening experiences throughout the day and transmit these data to the hearing

care professional to be used at the next HA fitting session; finally other apps allow the simulation of the hearing sensation the user will feel after using different types of HAs.

Hearing Rehabilitation Programs

Apps in this group address the needs of the 3rd target group. They are usually in the form of interactive games and use audio, video, graphics and written materials. This group includes (see Appendix 2):

1. programs that help to improve listening ability in difficult conditions (e.g. in noisy environments) featuring games that challenge both cognitive and auditory sharpness and help to train the auditory system in different soundscapes;

2. programs that improve articulatory and phonological abilities (available also for multi-lingual speakers);

3. applications designed to change in real-time the tempo of the speech captured by the smartphone for training people with brain lateralization dysfunction;

4. applications that improve speech articulation skills using animations to view tongue placement and positioning during pronunciation and virtually 'see inside the mouth' as the sounds are being made.

Finally, there are apps that serve as a board and activity creator for speech therapists, teachers, and parents of children who need symbols to communicate and learn. These new apps make at home rehabilitation feasible with procedures that are self-administered, that interact with the patient, and adapt to the specific disabilities and to the new skills achieved by the patient during the treatment.

Assistive Tools

These apps assist users belonging to the 4th target group, including those hard of hearing using sign language (see Appendix 2). Here we found: apps that add captions to phone calls in a way similar to TV captioning to aid people with hearing impairment to communicate over the phone; video dictionaries for those who need to communicate by sign language that show the signs corresponding to a given word, explaining how to perform the sign and giving useful memory tips to improve the association of a word to its corresponding sign; apps that help people with hearing difficulties to react to the audio environment by producing an alert (such as vibrations or flashes) when the phone or the bell door is ringing, or when someone is knocking or opening the door.

4 Conclusions and instant directions

In this paper we defined the new 'eHealth4Hearing' paradigm of health care. This new path potentially leads to a dramatic change both in the roles within the actors and in the way in which people's needs are addressed and solved. Differently from the traditional doctor-centric model (see Figure 1) in which the access to health care services, resources and solutions occurs mostly through the hearing care professional, now in the new 'eHealth4Hearing' care paradigm, people can have direct access to a wealth of solutions, health services and resources. We gave a number of examples of the practical implementation of such a new paradigm through the use of health apps. The use of health apps is leading to a potentially new scenario regarding how hearing health care will be delivered in the future, since it is now feasible to perform do-it-yourself tests, and can provide access to better health knowledge and technological solutions best suited to their hearing and communication skills. The mobile app technology here reviewed makes use of a mix of sensory channels (audio, video, graphics, and text) to deliver the health message to the subject. The integration of different sensory channels enhances patient interactivity and patient engagement with their health concerns and, thanks to the use of meaningful language, graphics, video and audio clips, it increases the degree of understanding of the messages, regardless of their level of health literacy.

Despite the many positive opinions in favor of the new 'eHealth4Hearing' paradigm, there are, of course, barriers and concerns for its full implementation. Just as an example, the availability of the "e-Health bus", the grounding element of the new 'eHealth4Hearing' paradigm, implicitly asks the actor of any autonomous search - patients included - to become responsible of the accreditation of the data source they decide to navigate, not only in respect true versus false contents, but also in understanding if the lexicons used on that source are sounding to their background. Also, the 'eHealth4Hearing' paradigm raises issues ranging from traceability to data privacy and security, from process modeling to business sustainability. A recent survey conducted by [35] documented that data security, citizen privacy (and their legal and policy regulation), assessment of effectiveness and cost-effectiveness are currently the most important key barriers for mHealth implementation. Similarly, the key messages summarized in [36] are: the need for high-quality health apps; the need for standards for quality assessment; the need for a common legislation/regulation in the EU. Generally speaking, the critical issues that should be addressed in the immediate future include:

1. the need to develop methods to assess app quality and effectiveness [37] including the reliability and repeatability of the self-administered tests, the reliability of the information delivered to the subjects, the safety ([38, 39]);

2. the lack of a legal framework concerning health apps;

3. the lack of interoperability among different healthcare system nationwide, and at a European level;

4. the lack of regulation for protection of data acquired by health apps ([40, 41]), responsibility risk [42], safety and/or misuse risk [43], informed use and trust ([44, 45]);

5. concerns about security, privacy, data ownership, protection, and use [46].

Last but not least, it is worthwhile to mention here other concerns that come directly from the use of unregulated apps by healthcare professionals and, more important, by patients [47]. If the use of apps by professionals potentially raises less concern, due to their background and their ability to detect incorrect or harmful information and to correctly interpret the indications given by the apps, patients might be much more vulnerable to misuse and wrong interpretation of the directions provided by the apps (for example, this can lead to unjustified anxiety or concern about the user health condition). In a way, while technology allows improving patient empowerment by giving, for example, more efficient methods of information retrieval, dissemination (regardless of its reliability) and services for self-management of health condition, on the other hand, the lack of regulation raises many concerns.

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Appendix 1 – The major target groups and how they face the new eHealth services. For each target group (see Section 2.1), the table shows the perceived needs (Section 2.2), the traditional healthcare and rehabilitation paths followed to address the perceived needs (Section 2.3), and, the new services that can be implemented with the eHealth4Hearing paradigm (Section 3.1). Some envisaged scenarios are also given that correspond to the 'wishing cases' illustrated in section 3: (*) Wishing Case 1 and 2; (**) Wishing Case 3.

Target groups	Perceived needs	Traditional healthcare and rehabilitation paths	The new 'eHealth4Hearing' services
#1: People needing/wishing to perform self-hearing assessment and monitoring	Sensitive testing towards life-long monitoring	Hearing tests are delivered by hearing care professionals/HA providers in clinical centres; monitoring is done through time-consuming checks.	*Self-testing:* home-based and self-administered hearing testing with cheap, fast and automated procedures delivered through smartphones or tablets(*)
#2: People needing amplification	Sound enhancement solutions towards flexibility and multi-sensorial integrations	Adjustment of the amplification settings of the HA is done through periodic and time-consuming fitting sessions with the audiologist or HA provider	*Sound Enhancement Solutions:* immediate and personalized sound enhancement implemented with smartphones; remote control and maintenance of hearing systems; remote consultation and individual engagement services (**)
#3: People needing hearing and communication rehabilitation	Rehabilitation programs towards best fitting and flexibility	Rehabilitation is done during face-to-face sessions with the therapist. When the patient is a young child, the required time and commitment of parents or relatives can be huge and hard to afford.	*Hearing rehabilitation programs:* feasible, at-home rehabilitation with procedures that are self-administered, that interact with the subject, and adapt to the specific disabilities and skills of the subject(**)
#4: People needing assistive tools (other than amplification)	Assistive tools to live more independently	Speakers or headphones to watch TV, listen to the radio or talk on the telephone are the conventional solutions. Sometimes there is no solution to deal with everyday sounds that cannot be heard	*Assistive tools:* smartphone-based, integrated solutions for a simple and ubiquitous way to assist communication and daily living
All groups	Education and information towards empowered user profiles	Education and information is accessible mostly through hearing care professionals	*Education and information services:* effective communication of health-related information regardless of level of health literacy through simulations, educational games, 3D animated atlases, exploiting the mixing of sensory channels (audio, video, graphics, and text) to deliver the health message to the subject

Appendix 2: The table shows for each of the five service groups considered in this paper, the number of downloaded apps, the name of the apps selected as the representative examples of the application of the mobile health to the new 'eHealth4Hearing' paradigm, the relevant features and the links to the sources. The selection was not exhaustive: it was mainly for showing the way the apps are tuned to the new paradigm.

Service Group	N	Selected apps	Relevant target group & Interesting features	Reference
Education & Information	46	3D Human Ear HD; Advent MD; Audiosense; EarAlmanac; Ear Match; LUMA Audiology; Otolaryngology-Dictionary; Tinnitus Awareness.	Target group: all users 3D interactive and animated atlases of anatomical structures; performance of simulations of impaired perception due to HI; monitoring in real time the level of sounds and produce alerts when they become potentially damaging.	https://itunes.apple.com/us/app/3d-human-ear-hd/id509787528 http://www.advent.md/ http://www.audiosense.dk/en.html https://itunes.apple.com/us/app/earalmanac/id383598535 http://www.bluetreepublishing.com/Details.cfm?ProdID=412&category=10 https://itunes.apple.com/us/app/luma-audiology/id428563241 https://play.google.com/store/apps/details?id=com.focusmedica.md.otolaryngology http://www.canterbury.ac.uk/news/newsRelease.asp?newsPk=2222
Self Testing	34	Hearing-Check; Hearing Kit; HearingTest4All; Siemens Hearing Test; Sound; Test Your Hearing; uHear.	Target group: people needing/desiring self-hearing assessment/monitoring Check and measure hearing functionality using tones, syllables or words embedded in noise; check hearing and measure the level of the environmental noise.	http://www.actiononhearingloss.org.uk/your-hearing/look-after-your-hearing/check-your-hearing/take-the-check.aspx https://itunes.apple.com/us/app/kit-ascolto/id471740125 https://itunes.apple.com/us/app/test-delludito/id414035034 https://itunes.apple.com/us/app/est-delludito-siemens/id394674665 https://itunes.apple.com/us/app/sound/id427587943 https://play.google.com/store/apps/details?id=net.epsilonzero.hearingtest https://itunes.apple.com/us/app/uhear/id309811822
Sound Enhancement Solutions	43	Solutions with Smartphones: Hear; EarMachine; HearYouNow; Better Hearing; Sound Focus.	Target group: people needing sound amplification but not wearing HAs Solutions with Smartphones: provide basic amplification; provide ad hoc amplification through pre-set programs; provide amplification shaped on the specific user hearing profile.	http://www.loyalty-foundation.com/products.html http://www.earmachine.com/ https://itunes.apple.com/us/app/hearyounow-your-personal-sound/id569522474 http://www.thegoodear.com/betterhearing http://soundfocus.com/

		Solutions with HAs: TrueLink; ConnectLine; ReSound Smart; Beltone SmartRemote; miniTek Remote; Hearing Diary; Phonak Lyric; Lifestyle Solutions.	Target group: HA wearers Solutions with HAs: allow remote control of volume and listening HA programs to suit the current audio environment; allows geotag localization to automatically adjust the listening program to that tagged location; perform counselling of the patients on their hearing status; capture and rate user personal listening experiences with the HA throughout the day to optimize HA fitting.	http://www.trulinkhearing.com/ http://www.oticon.com/products/wireless-accessories/connectline/app.aspx http://www.gnresound.com/Services/Smartapp http://www.beltone-hearing.com/Products/Beltone%20Apps/Beltone%20Smart%20Remote%20App https://global.hearing.siemens.com/products/wireless/minitek-app/ http://www.oticonusa.com/hearing/resources/educational-library/hearing-diary.aspx https://itunes.apple.com/us/app/phonak-lyric/id565850562 https://itunes.apple.com/us/app/lifestyle-solutions/id410700882
Hearing Rehabilitation Programs	42	Hear Coach; Bilingual Articulation Phonology Assessment; Speech Corrector; Speech Tutor; Auditory Processing Studio; Custom Boards Premium	Target group: people needing hearing and communication rehabilitation Features interactive games that challenge cognitive and auditory sharpness; personalized training of articulatory and phonological abilities; change in real-time of the tempo of the speech for the rehabilitation of people with brain lateralization disorders; use of animations and virtually 'seeing inside the mouth' during pronunciation to train people with articulation disorders; challenge listening and language skills by interacting with the user with images and animations; board and activity creator for speech therapists.	https://itunes.apple.com/us/app/hear-coach/id489515928 https://itunes.apple.com/us/app/bilingual-articulation-phonology/id460830225 http://sound.eti.pg.gda.pl/~kosiq/typo/speech_corrector_en.php http://pocketslp.com/#speechtutor http://www.virtualspeechcenter.com/Resources/auditory_processing_studio_app.aspx http://smartyearsapps.com/service/custom-boards/
Assistive Tools	13	TapTap; UNI; My Smart Hands Baby Sign Language Dictionary	Target group: people needing assistive tools Add captions to phone calls; video dictionaries for sign language; produce alerts to react to the audio environment.	http://www.taptap.biz/index.php http://www.motionsavvy.com/ http://mysmarthands.com/baby-sign-language-apps/
Total number	178	37		