Innovation in the Context of Audiology and in the Context of the Internet

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Abstract

Purpose This article explores different meanings of innovation within the context of audiology and the Internet. Case studies are used to illustrate and elaborate on the new types of innovation and their levels of impact.

Method The article defines innovation, providing case studies illustrating a taxonomy of innovation types.

Results Innovation ranges from minor changes in technology implemented on existing platforms to radical or disruptive changes that provide exceptional benefits and transform markets. Innovations within the context of audiology and the Internet can be found across that range. The case studies presented demonstrate that innovations in hearing care can span across a number of innovation types and levels of impact. Considering the global need for improved access and efficiency in hearing care, innovations that demonstrate a sustainable impact on a large scale, with the potential to rapidly upscale this impact, should be prioritized.

Conclusions It is unclear presently what types of innovations are likely to have the most profound impacts on audiology in the coming years. In the best case, they will lead to more efficient, effective, and widespread availability of hearing health on a global scale.

Agreement is widespread that audiology is changing due to innovations afforded by the Internet and smartphones. However, not all innovations have the same value, cost, or implications. Several panel discussions took place during the Third International Meeting on Internet & Audiology, July 27–28, 2017. In the last panel session, the authors of this article described their perspectives on innovation and entrepreneurship in the context of audiology and the Internet, which is the topic of the current report. A panel session from the Second Meeting on Internet & Audiology (September 24–25, 2015) was concerned with impediments to the use of hearing health care data. The authors stated that “today's disjointed landscape prevents the development and implementation of new solutions of benefit to professionals, users, and hearing care systems” (Laplante-Lévesque et al., 2016, p. 261). The innovation landscape today is no less disjointed. To impose some structure on its complexity, this article outlines a taxonomy of types of innovation and illustrates them with case studies in the context of audiology and the Internet. The authors here express some concerns that, in the absence of a framework to discuss and evaluate innovation, opportunities and resources may be squandered in developing products and services that are minor innovations, whereas only radical or disruptive innovation can solve pressing needs for hearing health care.

Worldwide, hearing loss is now recognized as a leading contributor to the global burden of diseases. It is the fourth leading cause of years lived with disability (GBD 2015 Disease and Injury Incidence and Prevalence Collaborators, 2016). Prevalence estimates for 2015 indicate that 1.33 billion people suffered from hearing loss, of which 473 million had disabling hearing loss (> 40 dB in the better hearing ear; World Health Organization [WHO], n.d.). More than 80% of persons with hearing loss reside in low- to middle-income countries (LMICs) where the vast majority are unable to access hearing health care services (Wilson, Tucci, Merson, & O'Donoghue, 2017). Even in high-income countries, the penetration of hearing health care services and uptake of interventions remain low. The costs associated with untreated hearing loss include psychosocial factors such as impaired communication, depression, social isolation, and cognitive decline (Wilson et al., 2017), with real-world annual costs of hearing loss estimated to be $750 billion (WHO, 2017a). In light of what is now known about the costs of hearing loss, the importance and necessity of innovation in the hearing care industry is clear and urgent.

A taxonomy of the impact of innovation and types of innovations at multiple levels was created for the software industry by Edison, Ali, and Torkar (2013) . Although we acknowledge that their taxonomy specifically focuses on software technology, we posit that it can also be usefully applied to areas of audiologic innovation that are coming to the forefront and will have a global impact on audiology. In addition, having a framework to discuss and evaluate these innovations is needed. Innovation in audiologic care and service delivery related to the Internet and mobile technology can be expected in different parts of the typical patient journey, including diagnostics, hearing device acquisition, fitting and fine-tuning hearing aids, counseling and training, and collection of data from patients, such as satisfaction ratings, general feedback, or expectations about future products and services.

Edison et al.'s taxonomy of impacts of innovations includes the following levels: (a) relatively minor incremental changes when they are based on existing platforms, where “platforms” here include services or delivery systems; (b) market breakthroughs when they are based again on existing core technology or platforms but provide a substantially higher benefit at the same cost; (c) technological breakthroughs when they are based on a substantially different technology but do not provide a superior customer benefit for the same cost; and (d) radical or disruptive innovations when they introduce new features or an exceptional benefit at a cost that transforms or creates markets.

The second level of the Edison et al. (2013) taxonomy concerns types of innovation. There are four types: (a) product innovation is the creation and introduction of technologically new or improved products that are significantly different from existing products; (b) process innovation changes the way products are created; (c) market innovation includes modified marketing, product design, and opening up new markets; and (d) organization innovation includes new business or clinical practices and remuneration systems. Table 1 lists the four types of impacts and the four types of innovation with the case studies below entered into the cells of the table.

Table 1. Taxonomy of innovation impacts and types.

Case study	**Innovation types**				**Innovation impacts**			
	Product	**Process**	**Market**	**Organization**	**Incremental**	**Market breakthroughs**	**Technological breakthroughs**	**Radical or disruptive**
1	X	X	X	—	—	X	X	X
2	X	X		—	X	X	—	X
3	X	X	X	X	—	—	—	X
4	—	X	—	X	—	—	—	X
5	X	—	—		—	X	—	—

Note. This taxonomy is adapted from Edison et al. (2013) . The cells in the table list the case studies that illustrate the innovations. Em dashes indicate data not applicable.

The forces driving current innovation are divergent. Case Study 1 describes a new model of service delivery using mobile technology and minimally trained laypersons for the early stages of the patient journey (i.e., detection, diagnosis, referral, and triage). This model was developed out of necessity, that is, the lack of audiologic infrastructure in LMICs. In contrast, Case Study 2 describes how the Internet can be used as a venue to deliver existing services that are currently underused (e.g., speech perception training) in a way that makes them more attractive to patients and clinicians. Case Study 2 also describes how the Internet and mobile technology can be used to collect real-time user feedback. The innovation impact in Case Study 2 is increased services through learning from (potential) users. Case Study 3 describes how changes in legislation can drive market innovation. Specifically, it addresses the recent U.S. over-the-counter (OTC) legislation, after which certain types of hearing devices for adults with mild-to-moderate hearing loss will be available without the involvement of a hearing care professional, thereby increasing accessibility and affordability and transforming the current hearing aid acquisition and fitting approach. The OTC model is closely linked to recent advances in hearing device technology regarding connectivity to other devices or the Internet. Case Study 4 describes how increased hearing device connectivity drives innovation in the audiologic care process toward a more patient-initiated rehabilitation path. Case Study 5 describes a market breakthrough for hearing testing.

Case Studies

Case Study 1: Market Innovation Through Necessity

Innovation impacts that range from market breakthroughs to radical or disruptive changes are appearing in the ear and hearing health care markets. It is not surprising that many of these new technology- and connectivity-driven digital health market innovations are from small digital health start-ups, often based in LMICs. The tremendous demand for hearing health care services globally, especially in LMICs, and the almost total dearth of available resources in regions such as sub-Saharan Africa (Mulwafu, Ensink, Kuper, & Fagan, 2017; WHO, 2017b) are driving market innovations. Although only preliminary evidence is available for many of the new approaches (Swanepoel, 2017b; Yousuf Hussein et al., 2016), a recurring focus is on decentralization of access to ear and hearing care while making services simple and efficient enough to be community based. New service delivery models have been made possible through rapidly evolving novel digital health solutions for detection, diagnosis, referral, triage, and interventions (Swanepoel, 2017b; Swanepoel, Myburgh, Howe, Mahomed, & Eikelboom, 2014; Yousuf Hussein et al., 2016). In high-income countries, the focus of these technologies and service delivery models is accessibility and affordability, with a strong drive to increase uptake and efficiencies in hearing care services in existing systems. In this sense, innovation in markets in high-income countries may be considered less radical than that in LMICs.

For example, in South Africa, a model that is presently being tried uses minimally trained persons to facilitate primary hearing care services and connected solutions that can make appropriate referrals to available hearing health providers based on location. Using low-cost smartphones connected to calibrated headphones allows the hearScreen and hearTest applications (hearX Group, Pretoria, South Africa) to facilitate rapid hearing screening and follow-up audiograms using minimally trained persons (Swanepoel, 2017b; Yousuf Hussein et al., 2016). Designed to simplify and automate the test procedures, these mHealth tools also incorporate rigorous, advanced-quality control measures such as real-time noise monitoring, test operator, and patient quality indices, so that a decentralized, mobile, service delivery model can be supported. Furthermore, linking these smart hearing test devices to a cloud-based data management system allows for location-based referrals via text message, surveillance, specialist support, and advanced reporting.

According to the Edison et al. (2013) taxonomy, the innovations here cover product process and market innovation types. The product innovation has its primary impact as a technological breakthrough allowing for low-cost, automated, mobile audiometric testing by minimally trained laypersons (see Table 1). The process innovation entails a change in the way products are created by utilizing off-the-shelf hardware with proprietary software to allow dedicated medical applications. The market innovation impacts across market and product breakthrough and disruptive elements. The technology, including the point-of-care mobile diagnostic and cloud data management, facilitates new market exploitation with the technological breakthroughs and allows a radical or disruptive impact for accessibility of hearing health care using simple low-cost connected solutions that minimally trained persons can operate, a radical departure from audiologic practice carried out by individuals with postgraduate education. The platform also offers a smartphone-connected otoscope (hearScope) that makes capturing an image of the tympanic membrane simple. This approach affords the possibility of an image-based diagnosis using a proven artificial intelligence image-based analysis approach (Myburgh, Jose, Swanepoel, & Laurent, 2018; Myburgh, van Zijl, Swanepoel, Hellström, & Laurent, 2016).

These innovations enable novel service delivery models that were impossible in LMICs and high-income countries (Swanepoel & Clark, 2018). As these technologies enable new service delivery models, they also may encounter difficulties in gaining acceptance in more established markets as is often observed with disruptive innovations. For example, there may be reluctance to distribute service provision among trained and minimally trained persons in high-income countries that have long-established audiologic services carried out by individuals with higher degrees. This type of solution utilizing point-of-care smartphone diagnostics integrated with a cloud-based data management facility is also scalable to other solutions. For example, this smartphone and cloud platform supports the integration of other related and complementary services such as vision screening, that is, the possibility to provide community-based hearing and vision test, referral, and data management services, again using minimally trained persons (example project: https://www.youtube.com/watch?v=SDWltCfbPrY).

Case Study 2: Innovation Through Learning From Potential Customers

A common belief among researchers is that eventually their work will benefit society. The researchers' work is typically driven by the researchers' definition of the problem. This approach has been notoriously unsuccessful in producing real products. The gap between federally funded research in the United States and new commercialized technology is referred to as the “valley of death,” where new technologies go to die. The U.S. Small Business Innovation Research grants that are awarded by the U.S. National Science Foundation and the National Institutes of Health have too often failed to result in viable businesses, and consequently, society fails to benefit from the technologies and/or science that was supported. The National Science Foundation diagnosed the problem of the valley of death as the result of researchers and engineers building things that nobody actually cares about. The NSF Innovation-Corps Teams program (http://www.nsf.gov/news/special_reports/i-corps/index.jsp) focuses on teaching researcher teams about product, process, and market innovations. It focuses on a product development process that is driven by discovering who the customer is, what their needs are, and how the product can be marketed profitably.

Bernstein and colleagues (S. P. Eberhardt, G. Miller, and E. T. Auer) from George Washington University set out to determine whether there was a market for an innovative Internet-based approach to speech perception training to support better audiovisual (AV) speech perception in noise by individuals with hearing loss. The Internet is an obvious venue for speech perception training, and a variety of applications are already becoming available, but the impetus for training programs appears to have come from clinicians and researchers exclusively. There is no evidence that potential trainees have had an impact in determining the design of the training programs, beyond participating as test or clinical users.

The rationale for speech perception training from the researchers' perspective seems straightforward. Even in the absence of elevated auditory thresholds, many older adults experience difficulties perceiving speech in noisy settings (Humes et al., 2012; Pichora-Fuller, Schneider, & Daneman, 1995; Sommers, Tye-Murray, & Spehar, 2005; Tye-Murray et al., 2008), and even with hearing aids, difficulties persist, because hearing aids do not adequately compensate for auditory distortions and poor signal-to-noise ratio (SNR; Gordon-Salant & Fitzgibbons, 1999; Pichora-Fuller & Souza, 2003; Sheft, Shafiro, Lorenzi, McMullen, & Farrell, 2012). One possibility is that auditory training approaches can be developed that overcome difficulties that arise during conversational speech in noise. However, about a decade ago, a meta-analysis (Sweetow & Palmer, 2005) of adult audiologic rehabilitation studies found only six studies that met inclusion criteria for scientific methods and concluded that there was "very little evidence for the effectiveness" of auditory speech perception training. More recently, modest results from auditory training have been reported (Anderson, White-Schwoch, Choi, & Kraus, 2013; Chisolm & Arnold, 2012; Henshaw & Ferguson, 2013; Humes, Burk, Strauser, & Kinney, 2009; Karawani, Bitan, Attias, & Banai, 2015). Thus, although the Internet and home computer would seem a perfect solution for delivering a training product, there does not appear to be a breakthrough product yet available.

Bernstein's Innovation-Corps team questioned who might care about such a product beyond researchers working on the problem. Initially, the team thought that a training system might be useful to and distributed through audiology practices. Thirty-six individuals with degrees in audiology from across the United States and in Europe and Australia were interviewed.[1] Many of the interviews were carried out using Internet videoconferencing applications. They covered a spectrum of activities from being hearing aid providers, rehabilitation audiologists, clinic directors, and researchers. They were asked about their familiarity with a variety of software or Internet products for training auditory speech perception and/or lipreading. Their overall assessment was that these products might be useful to some patients but had not yet delivered sufficient levels of success to warrant enthusiasm. The audiologists who identified as "rehabilitation audiologists" were generally more interested in Internet training geared toward learning life skills to cope with hearing loss. Rehabilitation audiologists were knowledgeable about the limitations of available speech perception training programs for older adults with hearing loss. The team concluded that a speech perception training system would need to have shown a significant benefit beyond what has been reported through scientific testing before clinicians could be regarded as customers or recommenders for the system.

The interviewers thought that lipreading training could be attractive to older adults with hearing loss, because noisy situations frequently afford visual and auditory speech information, and AV speech can functionally improve SNR. However, the functional improvement varies substantially across individuals. A significant proportion of the individual variation may be attributable to visual speech perception ability (Grant, Walden, & Seitz, 1998; Ross, Saint-Amour, Leavitt, Javitt, & Foxe, 2007; Summerfield, 1991). This individual variation and its role in the benefit obtained with AV speech have implications for ameliorating difficulties during face-to-face communication. Specifically, effective training on visual speech perception can generalize to AV speech perception in noise. Furthermore, given that most adults who have experienced healthy hearing throughout most of their lives are poor lipreaders (Auer & Bernstein, 2007; Bernstein, Demorest, & Tucker, 2000), there is ample room for improvement. However, the question was whether this potential solution matters to older adults with hearing loss. Forty-seven adults with hearing loss, the majority older, were interviewed about their hearing health needs and experiences and their possible interest in an Internet-based training system. Many of the interviews were carried out using Internet videoconferencing applications. These interviews identified subgroups with different experiences of hearing health and different needs and desires. Training was not deemed attractive by those with mild-to-moderate hearing loss and who were relatively satisfied with their hearing aids. In contrast, training was viewed as potentially attractive to those with more severe hearing loss and with difficulty using hearing aids in noisy social situations.

However, there were several significant caveats that the team learned about within this latter group. First, interest in training would be limited if the users could not quickly discern benefits. That is, if their subjective impression was that they were not learning enough or quickly, they would be likely to lose interest. Second, they did not want to be bored, but they were also not generally interested in gamified training. They were not interested in a training experience that was not respectful of their interests or level of maturity. Third, they expressed willingness to pay for training if it were effective. They knew that their problems were significant and would put money into effective solutions. Fourth, their potential interest in training depended on how the topic was introduced during the interview. A common pattern was to reject the idea of learning to lipread and yet to embrace the idea that being able to use visual speech information would be helpful, suggesting that education about the benefits of AV speech perception and its reliance on lipreading ability would be needed by some individuals to motivate training.

Although most scientific research projects on training use small amounts of pay to participants to use the training system and to acquire scientific data, a successful product would have to involve an investment on the part of the trainee. Even if training were free, the trainee would have to decide to invest time and energy in the training. Therefore, a training product would have to be radically more effective and more engaging than any products to date. Interviews suggested that it would need to have a far different “feel” than anything that has come out of the laboratory or clinical research. For example, it may need to be wrapped in a lifestyle product or social media context. The process of developing such a product may come through the Lean Startup model (Blank & Dorf, 2012), which is designed to quickly develop minimal viable products to test product attractiveness. The minimal viable product process is radically different from the laboratory development process that invests large amounts of resources to obtain scientific evidence in advance of investigating customers' preferences. A commercially viable product may need to demonstrate customer engagement before or in tandem with scientific proof. Case Study 2 is listed in Table 1 as a radical product in the sense that a lipreading training system would attempt to solve the speech-in-noise perception problem through improved AV speech processing and would also require long-term engagement with training. The approach to development is also potentially radically different from development within the laboratory or clinical impetus.

Rather than interviewing people to learn about their experiences, it is also possible to use mobile technology and smartphone connectivity to collect data from them in real time. Timmer, Hickson, and Launer (2017) have recently shown how an ecological momentary assessment can be used to acquire subjective ratings of listening situations from hearing aid users, while they are in specific situations. Hearing aid users filled in very short surveys on a smartphone about several aspects of the listening situation they were experiencing. The surveys could be initiated by the user, could be triggered at random times during the day, or could be triggered based on criteria of the acoustic environment, monitored by the hearing aid. The hearing aids tracked data such as estimated overall sound level, SNR, and percentage of speech, noise, and music in the environment. Ultimately, the subjective user ratings and technical measurements from hearing aids could be linked to improve hearing aid signal processing in general or situationally. This example is listed in Table 1 as an incremental market innovation with regard to hearing aids, as they use existing technology. However, it is also possible to imagine more radical uses of an ecological momentary assessment that might, for example, be coupled with artificial intelligence to carry out listening or communication tasks that are too difficult for a hearing aid user.

Case Study 3: Innovation in Device Accessibility and Affordability Through Legislation and OTC Products

OTC hearing aids are perceived as a disruptive innovation in the field of audiology as well as an overdue response to unmet needs on the part of consumer advocates. In Table 1, Case Study 3 is listed as having a radical impact as a product and a process.

The U.S. Over-the-Counter Hearing Aid Act of 2017 was signed into law requiring that OTC hearing aids are for individuals with mild-to-moderate hearing loss. It requires that the hearing aids meet the same safety, consumer labeling, and manufacturing protections that all other U.S. medical devices must meet. According to The National Academies of Sciences, Engineering, and Medicine, “This approach would enable consumers and patients to take more control over their own health conditions. The committee also emphasizes the need for greater transparency through the unbundling of prices for hearing health care services and related technologies and raising awareness of patients' rights of access to their hearing health care information and records” (The National Academies of Sciences, Engineering, and Medicine, 2016).

The OTC movement was primarily triggered by issues concerning hearing aid access and affordability (The National Academies of Sciences, Engineering, and Medicine, 2016). However, the impact of disruption that is arising from OTC hearing aids is expected not only at a local level but also globally. Issues surrounding accessibility and affordability are evident not only in consumer-driven markets but also where the provision of hearing aids is free; hearing aid uptake and use are relatively low, irrespective of the health care system (Barker, Mackenzie, Elliott, Jones, & de Lusignan, 2016). Untreated hearing loss in older adults has become an even greater concern given its association with other health conditions, including anxiety and depression (Ciorba, Bianchini, Pelucchi, & Pastore, 2012), and an increased risk of developing dementia (Lin et al., 2011). Thus, the ultimate goal of OTC hearing aid provision is to substantially increase market penetration and thereby dramatically reduce the negative individual and societal consequences of untreated hearing loss. For these reasons, it is perhaps unsurprising that alternative service delivery models are being considered that aim to improve accessibility of hearing services for people living with hearing loss who do not (or cannot) access hearing aids.

A recent scientific study (Humes et al., 2017) examined some possible effects of the OTC market on patients. Its results suggest that, even with comparable benefits in speech understanding, patients who do not have any contact with an audiologist during the rehabilitation process will be less satisfied with their hearing aids, exhibit poorer hearing aid handling skills, and experience higher perceived aided hearing handicap. However, the availability of OTC hearing aids is likely to result in changes in patient behavior that cannot be reliably predicted at this time. For example, online reviews of hearing aid buying and using experiences may result in a more accurate understanding of the advantages and disadvantages of particular OTC hearing aids as well as other types of practical advice. Clearly, these are "early times" in this market.

Case Study 4: Patient-Driven Rehabilitation

This case study is listed as a disruptive innovation regarding process and organization, because connectivity of hearing devices and the resulting implications for audiologic care have the power to transform the current market by changing business practices. Heretofore, audiologic services and products have been provided almost exclusively by clinicians with specialized knowledge and equipment in the setting of an audiology clinic. The patient visits the clinic for all of his or her hearing health concerns (e.g., assessments, counseling, hearing aid fittings and fine-tuning, hearing aid maintenance and repair, and purchasing of batteries and accessories). The patient-initiated consultation sets the clinician's procedures into motion. The emergence of new distribution channels for standard hearing devices, such as online purchases, and the introduction of OTC products imply that patients can exert more control over and have more responsibility for their own hearing rehabilitation.

In a patient-driven model of audiologic care, both the patient and the clinician take responsibility and actions for successful hearing rehabilitation, but the extent of clinician involvement is determined by the patient to a greater extent than in the traditional model. The OTC buyer will self-test hearing, select/fit a hearing device, manage device maintenance and repair, and develop everyday strategies for functioning with a hearing loss. These options may be facilitated by developments in mobile technology and hearing device connectivity that enable adjustment of hearing aid settings by the patient, using nonprofessional equipment. Additional benefits could be created if clinicians were available for professional paid services at each stage of the rehabilitation process. For example, the patient could choose to get an additional audiologist checkup for ear canal blockage due to cerumen before self-fitting his or her hearing aids. The audiologist could be consulted to solve issues during fitting, such as making real-ear measurements or fine-tuning, helping with hearing device repairs, and so forth. Patients thus become the initiators, and clinicians act as resources for problems that cannot be managed alone. Because of a greater connectivity in hearing devices through Bluetooth and Internet and because of the integration of remote-fitting options available to the clinician, parts of the hearing rehabilitation collaboration between patient and clinician can be performed while the patient and the audiologist are in different geographical locations. Such an approach increases the accessibility of audiologic services, especially for patients living in rural areas or parts of the world where audiologic clinics are scarce. It also saves time for the patient and increases access for people who are not mobile enough to visit a clinic. Remote hearing care sessions can be used to test hearing aid fittings real time in the patients' living environment and together with their family, increasing patient-centeredness.

Audiologists may also be coaches and counselors on questions of hearing health (Grenness, Hickson, Laplante-Lévesque, Meyer, & Davidson, 2015; Meibos et al., 2017). For example, psychosocial counseling was found to positively influence the patient's hearing rehabilitation decisions and increase the success of hearing care (Ekberg, Grenness, & Hickson, 2014). Counseling can benefit communication strategies; reduce anxiety, hearing handicap, and disability; and reduce restrictions on activity and participation (Aazh & Moore, 2017).

In a study by Maidment and Ferguson (2017), the views of 20 adults living with mild-to-moderate hearing loss were explored concerning usability, delivery, accessibility, and acceptability of and adherence to a broad range of smartphone-connected listening devices. Such devices require limited or no audiologic input because they can be fitted and/or adjusted by the users themselves via a smartphone. Existing hearing aid users trialed one of the following devices in their everyday lives for a period of 2 weeks: smartphone-connected hearing aids, personal sound amplification product, or smartphone hearing aid–type application used with wired or wireless earphones. After 2 weeks of use, semistructured interviews were completed. Preliminary analysis suggests that users want to personalize and adjust their own listening devices using a smartphone to improve their ability to communicate in any situation. This subsequently provides the user with a greater sense of control, resulting in less frustration, greater participation, and more device use. This study will be used to inform the design of further high-quality evidence-based assessment of the clinical effectiveness and cost-effectiveness of alternative audiologic service delivery models that innovations in smartphone technologies enable (see Maidment & Ferguson, 2017).

Case Study 5: Innovation Through Entrepreneurship

When considering innovation through entrepreneurship, it may be useful to make a distinction between traditional conceptions of entrepreneurship that are concerned with generating personal/shareholder wealth and those that focus on the creation of products, services, and/or organizations to improve social outcomes for a specific stakeholder group (i.e., social entrepreneurship; Phillips, Lee, Ghobadian, O'Regan, & James, 2015). Philips et al. posit that social entrepreneurship and innovation share common overlaps, whereby social entrepreneurs exploit (or harness) innovative activities and/or services to address unmet social needs or promote social developments. As such, social innovation is not simply undertaken by individual entrepreneurs working in isolation but involves a wide range of individuals, organizations, and/or institutions working collectively to bring about social change (Phillips et al., 2015).

In the context of audiology and the Internet, one such example of social entrepreneurship is the development and launch of a consumer smartphone application as a national hearing test (Potgieter, Swanepoel, Myburgh, Hopper, & Smits, 2016; Potgieter, Swanepoel, Myburgh, & Smits, 2018). On World Hearing Day 2016, the hearZA smartphone application was launched as South Africa's national hearing test, facilitating a free hearing test to every South African from their smartphone. The test, which uses a digits-in-noise test paradigm determining speech perception ability in background noise, provides a result in 2 min. The hearZA application is employed as (a) a strategic public awareness tool for hearing health, (b) an accurate screening tool for hearing loss, (c) a personalized hearing health tracker, (d) an in-app decision support tool encouraging action on hearing loss, and (e) a referral network to link people to their closest hearing health providers based on geolocation in partnership with national audiologic societies (Swanepoel, 2017a).

This social entrepreneurship endeavor is a product innovation with its primary impact as a market breakthrough offering extensive free hearing health services to the public (see Table 1). As a social innovation, it was developed and validated at the University of Pretoria and made available commercially by the hearX group (Pretoria, South Africa; Potgieter et al., 2016, 2018). To ensure that the national hearing test app can be offered free of charge, strategic partnerships with various sponsors, of which the largest mobile operator in South Africa (Vodacom) is the primary sponsor, needed to be developed alongside the support of the national audiology associations (Swanepoel, 2017a). The success of this social entrepreneurship project has seen almost 50,000 persons tested and thousands referred to local hearing health specialists. South African celebrities serve as hearing health ambassadors for the application (see https://www.youtube.com/watch?time_continue=2&v=ULBpdo_k-mg) and support the national marketing and advocacy campaigns to ensure the ongoing success of this initiative.

This technology also covers a type of organizational innovation with impact in the market breakthrough segment (see Table 1). The referral system linking patients directly to audiologists according to test and clinic geolocation provides new verified leads to patients requiring services and amplification. This generates a new business opportunity with the possibility of also placing hearing test kiosks in community-based locations such as pharmacies, general practitioner offices, and optometry practices.

General Discussion

Innovation has accelerated with the growth and advancements in the Internet and mobile devices, and audiology is changing as a result. However, adoption of innovation, especially in health care, is often delayed due to market resistance from health providers. Part of the challenge is to appropriately classify and review innovations within a larger framework. As argued at the outset of this article, the innovation landscape today is somewhat disjointed, not least because the forces driving innovation tend be quite divergent. In the present article, we have attempted to address this. Namely, the taxonomy provided by Edison et al. (2013) and illustrated by the case studies considered above allows for a more holistic view of innovation types and their respective impact.

An interesting outcome of using the Edison et al. taxonomy is the observation that many of the innovations in the case studies are expected to deliver more than one type of impact. In addition, many of the innovations were considered to be radical, inasmuch as they are expected to alter the practice of audiology while increasing the range of products and services that may hopefully become universally available at affordable prices.

Case Study 1 describes an innovative model of service delivery using mobile technology and minimally trained laypersons for the stages of detection, diagnosis, referral, and triage of hearing loss. To do this requires technical breakthroughs and radical changes in the process and marketing of audiologic services. Such developments were driven by necessity, that is, the dearth of audiologic infrastructure in LMICs. Case Study 2 describes a customer discovery process that is typically not carried out in the context of research studies concerning speech perception training, including lipreading training. It revealed that training products, no matter how effective they might be in the laboratory, would have to also incorporate approaches that would make them attractive enough to keep users engaged over extended periods and even pay for use of the training platform. It is not presently clear how this might be accomplished. Case Study 2 also pointed out that an ecological momentary assessment could be used to understand patient needs. Case Study 3 outlines market innovation through legislation and consumer advocacy. Although legislation and advocacy are not themselves radical innovations, the recent passage of the OTC hearing aid legislation in the United States is expected to have innovation impacts that are felt to be radical by both audiologists and patients. Case Study 4 described how the Internet and the consumer market for hearing devices could redefine how professional audiologist services are used by patients, another potentially radical innovation at the level of markets. Case Study 5 introduced the concept of social entrepreneurship used to achieve market breakthroughs. A free national hearing test with direct links to providers has the potential to be an almost universal funnel connecting individuals with hearing health problems to solutions.

Conclusion

Audiology as a profession has always been closely tied to technological innovations. With the advent of the Internet and rapid growth in technology connected to the Internet, health care is seeing an unprecedented rise in innovation, and hearing health care is no different. The innovations discussed in this article point toward development of hearing health care that will grant both higher accessibility and greater affordability of hearing devices and audiologic services. These services address all of the stages of the patient journey, from screening to device fitting, coaching on hearing device usage, and auditory and speech perception training. Thus, the field of audiology is evolving to serve more people, earlier, with higher-quality services than ever before. This is a great opportunity for our profession, and it is our responsibility to make sure that the potential will be realized. We need to cultivate a culture that values innovation and that quickly incorporates evidence-based innovations to reach more patients and improve patient outcomes.

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