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Argumentum ad ignorantiam: Smartphone-connected listening devices

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Argumentum ad Ignorantiam: Smartphone-Connected Listening Devices

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Abstract

In this paper, we review the current literature assessing the application and benefits of “connected” hearing technologies, as well as their potential to improve accessibility to and affordability of hearing healthcare. Over the past decade, there has been a proliferation of hearing devices that connect wirelessly to smartphone technologies via Bluetooth. These devices include: (1) smartphone-connected hearing aids that must be obtained from a licensed audiologist or hearing aid dispenser; (2) direct-to-consumer (DTC) devices, such as personal sound amplification products (PSAPs); and (3) smartphone-based hearing aid applications (or apps). Common to all these connected devices is that they permit the user to self-adjust and customise their device programmes via an accompanying smartphone app. There has been a growing body of literature assessing connected hearing devices in adults living with hearing loss. Overall, the evidence to date supports the notion that all connected hearing devices can improve accessibility to and affordability of amplification. It is unclear, however, whether connected technologies are a clinically effective alternative to traditional hearing aids. Even so, the impact of connectivity is especially pertinent given the sudden disruption caused by the recent global COVID-19 pandemic, whereby connected technologies enable patients to receive treatment through mobile-based, tele-audiology platforms.

Learning Objectives

After reading this article, the learner will be able to:

- summarize the evidence assessing different connected hearing devices;
- explain how connected hearing devices compare to traditional hearing aids; and
- discuss whether connected hearing devices can improve accessibility to and affordability of hearing healthcare.

Keywords: Hearing Aids; Hearing Loss; Personal Sound Amplification Products (PSAPs); Smartphone; Applications (Apps).

Conflict of Interest: None.

INTRODUCTION

Hearing loss is a highly prevalent global burden of disease, affecting an estimated 466 million people worldwide [1]. By 2050, prevalence figures project that roughly 900 million individuals will be affected by disabling hearing loss, given the unprecedented growth in the aging (i.e. 65+ years) population. Hearing aids are the primary clinical intervention strategy for cochlear hearing loss and have been shown to effectively improve the user's quality of life and listening abilities [2]. However, most adults who would benefit from hearing aids do not adopt them. This is particularly vexing given the current global pandemic, where the aging population may be faced with receiving medical care without typical familial support and experience an inability to communicate effectively with healthcare providers.

Less-than-ideal hearing aid adoption is influenced by several factors, one of which includes high “out-of-pocket” costs associated with hearing healthcare. In the United States (US), where the cost of hearing healthcare is not always reimbursed by medical insurance, the most recent hearing aid adoption rate is estimated at 34% [3]. While adoption rates are better in countries where provision is subsidized or completely free-of-charge from publicly-funded healthcare services, uptake is still only around 40% [3]. Additionally, low acceptance of hearing aid acquisition is associated with enhanced self-perceived activity limitations and participation restrictions, reduced hearing aid self-efficacy, as well as a lack of social support to manage hearing loss [4,5]. The negative stigma associated with hearing loss and hearing aids has also been identified as a key barrier to help seeking [6-8].

Accessibility to hearing healthcare, defined as “*the timely use of health services to achieve the best possible health outcomes* [9]”, affects adoption rates negatively, especially when clinic-based service delivery models do not always adequately meet the needs of older adults

living with hearing loss [10]. This is particularly true for impaired listeners with reduced mobility or those who reside some distance from their nearest clinic. Research indicates that it can take an individual roughly six to eight years to access intervention once their hearing difficulties emerge [11]. In the US, an estimated 14.6 million Americans live with an untreated hearing loss, which costs the economy approximately \$133 billion each year due to lower quality of life and lost productivity owing to higher rates of unemployment [12]. The high prevalence of untreated hearing loss is also associated with an increased risk of developing other chronic health conditions. These conditions include cardiovascular disease [13,14] and diabetes [15,16], as well as cognitive impairment and dementia [17,18], which are the main causes of morbidity and mortality worldwide. Given barriers to hearing aid adoption, alternative interventions are critical. Moreover, the current impact of the COVID-19 pandemic has highlighted that there is a desperate need to address sudden and unprecedented disruption of access to audiological care when businesses and clinics are mandated to close and individuals are required to minimise or eliminate all contact with others from outside their household.

Mobile Technologies as an Intervention

Health practices that are supported by mobile devices—such as mobile phones, tablets, patient monitoring devices, and personal digital assistants (PDAs)—can be referred to as mHealth [19]. MHealth technologies could provide a means of addressing some of the key barriers in hearing healthcare already discussed. For example, within the last 10 to 15 years there has been a proliferation of hearing devices that connect wirelessly, either directly or indirectly (i.e., using an intermediary device such as a dongle), to smartphone technologies via Bluetooth. These devices include personal sound amplification products (PSAPs) and smartphone-based hearing aid applications (or apps), both of which (i) cost significantly less

than hearing aids, and (ii) can be obtained directly by the consumer without consultation from a hearing healthcare professional. In some instances, these direct-to-consumer (DTC) amplification devices enable the user to self-adjust the gain and frequency response via an accompanying smartphone app.

Similarly, smartphone-connected hearing aids also permit the user to self-adjust and customise their device programmes via an accompanying smartphone app; however, these devices must be obtained from a licensed audiologist or hearing aid dispenser. In addition, smartphone-connected hearing aids integrate additional functionalities, such as direct-audio streaming (e.g. phone calls, music), geotagging for location-based configuration, physical activity monitoring, and remote programming by a provider [20].

In line with the technological advances described, there has been a growing body of literature assessing “connected” hearing devices in adults living with hearing loss. In this paper, therefore, we review the current literature assessing the application and benefits of: (1) smartphone-connected hearing aids, (2) DTC amplification devices, and (3) smartphone-based hearing aid applications (or apps). We will also discuss the potential for each category of technology to improve accessibility to and affordability of hearing healthcare, particularly during these challenging pandemic times.

1. SMARTPHONE-CONNECTED HEARING AIDS

Traditional hearing aids are programmed and adjusted to an individual’s prescribed target gain by a licensed audiologist or hearing aid dispenser using specialist equipment. The audiologist or dispenser can also enable the device’s volume control and/or additional programmes, which can be manually operated by the user via a switch on the hearing aid or

via an intermediary device, such as a remote control. In the last decade, the introduction of direct or indirect (i.e., via a dongle) wireless streaming via Bluetooth allows for the connection of compatible hearing aids to smartphone technologies. Smartphones provide an interface to hearing aids via an app, which enables the user to adjust their hearing aid programmes conveniently in any listening situation to meet their listening needs and/or preferences.

Hearing aids that connect to smartphones are classified as either MFi or MFA. MFi stands for “*Made-for-iPhone/iPod/iPad*” and is a licensing program available from Apple to developers of hardware and software peripherals. The licensing program permits connectivity between the iPhone and, for example, the hearing aids. In 2014, ReSound was one of the first hearing aid manufacturer to take advantage of this connectivity, which resulted in the launch of their Linx product line [21]. Today, all five major manufacturers offer a MFi hearing aid product line. The primary benefits of MFi hearing aid technology are (i) wireless audio streaming (e.g., phone calls, music), (ii) wireless TV streaming, and (iii) remote control functionality via a dedicated app. MFA, on the other hand, is used interchangeably for both “*Made-for-All*” (MF-All) and “*Made-for-Android*” (MF-Android). MF-All is designed to stream direct audio from any Bluetooth-enabled smartphone, while MF-Android is designed to stream direct audio from compatible Android smartphones only. Hearing aids manufactured with MF-All were introduced in 2018, with the ability to connect a single hearing device to a smartphone using Bluetooth Low-Energy (BLE) technology. In 2019, Phonak and Unitron released the Marvel and Discover lines, respectively, that utilized MF-All allowing one hearing aid to connect to the smartphone using Bluetooth, and that same connected hearing aid then also transmits a data stream to the second hearing aid to create a binaural audio stream. In 2019,

MF-Android became available in ReSound and Starkey product lines using BLE technology, which is compatible on Android phones that use Android-10 operating system (or later).

Recently, Ng et al [22] employed a qualitative, collective case study design to investigate US-based clinician and patient experiences of smartphone-connected hearing aids. A key advantage of the authors' approach was that it drew upon multiple perspectives and sources, providing an in-depth insight into the phenomena of interest [23]; that is, the wireless connection of hearing aids with smartphone technologies. In total, eight clinicians and 11 patients were interviewed, and their data triangulated with 10 grey literature sources (e.g. news media, published reports from associations/other agencies, articles in professional magazines/trade journals/on professional websites) published between 2014 and 2015. From these sources, Ng and colleagues [22] found that perceived smartphone competency had an impact on clinicians' judgements concerning patients' candidacy for smartphone-connected hearing aids, as well as how confident patients felt about learning to use these devices. Clinicians reported that their aural rehabilitation practices were improved by the provision of smartphone-connected hearing aids, as they spent more time getting to know their patients' listening and communication needs/preferences. In addition, both clinicians and patients reported that connecting smartphones with hearing aids had the potential to reduce stigma, as smartphone technologies were perceived as more socially acceptable (or 'normalised') in comparison to traditional hearing aids. It was also stated that smartphone-connected hearing aids provided greater opportunities for patients to participate more fully in everyday life. Nevertheless, not all findings were positive, with technical issues related to Bluetooth connectivity and troubleshooting resulting in patients experiencing frustration and increased burden.

The findings from Ng et al. [22] have been further supported by a recent prospective, observational mixed methods study assessing the benefits of smartphone-connected hearing aids in new and existing users [24]. In this study, Habib et al [24] recruited patients from the publicly funded United Kingdom (UK) National Health Service (NHS). Forty-four patients (n= 14 new; n= 30 existing) trialled smartphone-connected hearing aids for a period of seven-weeks in their everyday lives. Patient-reported outcomes revealed several benefits of smartphone-connected hearing aids, including improvements in social participation, hearing-related fatigue, quality of listening through hearing aids, and hearing aid benefit and satisfaction. For existing hearing aid users, all outcomes were significantly better for the smartphone-connected hearing aids in comparison to their conventional NHS hearing aids. Additionally, focus groups in sub-set of patients (n= 8) suggested that the most useful feature of smartphone-connected hearing aids was the ability to adjust the sound quality via the app. This feature was particularly advantageous when conversing with others in the presence of background noise, such as in a busy restaurant or pub. Moreover, patients reported that user-controllability empowered them to self-manage their hearing loss, providing them with a greater sense of confidence and autonomy, leading to greater social participation.

In addition to assessing user-controllability via an app, a number of studies have also evaluated the usability and effectiveness of making remote requests to adjust their hearing aid programmes and to receive new settings from their audiologist [25,26]. For example, Groth and colleagues [25] compared the quality of fine-tuning hearing aids performed by an audiologist either in-person or using ReSound Assist, the latter of which is an asynchronous smartphone app-based tele-audiology service for fine-tuning manufacturer-proprietary devices. For speech-in-noise performance, which included a subjective assessment of benefit, fine-tuned changes for the two methods did not differ significantly. This finding led the

authors to recommend introducing the tele-audiology tool for use after the initial fitting and in-person follow-up as part of the routine clinical protocol, where the two methods would supplement one another in improving affordability (e.g., costs associated with transportation) and accessibility (e.g., appointment availability).

Similarly, Convery et al [26] randomly allocated 30 patients to one of two groups: (i) an intervention group, where patients could report any hearing aid problems to their audiologist via the ReSound Assist app; or (ii) a control group, where patients could only report their problems at a face-to-face follow-up appointment at the end of the six-week field study. Most patients (11 of 15) were able to access the app successfully in order to report a problem to their audiologist and/or upload new hearing aid settings. Findings revealed that there were no significant differences between groups in terms of hearing aid outcomes (i.e. hearing aid use, benefit, and satisfaction, as well as speech understanding in noise), suggesting that remote communication between patients and audiologists via the app is equally efficacious as face-to-face follow-up appointments, at least in the short-term [26].

Patients with hearing loss also have the option of using either the Listen Live feature on their Apple device (i.e., iPhone/iPad/iPod) or the StreamLine Mic feature on their Android device. In both cases, this technology allows the user to enable the microphone of their smartphone to transmit audio to either a set of paired hearing aids or earbuds. Such a technology could be used like remote microphone (RM) systems, which have been shown to improve speech understanding in adverse listening environments, but at a fraction of the cost. Research suggests that when aided performance of the Listen Live app coupled to a traditional hearing aid is compared to a RM system using the same hearing aid in listeners with and without hearing loss, improvements in speech recognition in noise are similar [27].

Lastly, there is a growing body of evidence highlighting that smartphone-connected hearing aids provide multiple benefits, including user-centred adjustment and customisation, as well as remote fine-tune programming (see Chasin [28] for examples of manufacturer-specific details). As a result, it is anticipated that, as additional functionalities continue to be introduced, smartphone-connected hearing aids will provide increasing opportunities to innovate adult aural rehabilitation practices. To this end, further evidence will be needed to determine the extent to which the additional functionalities provided by smartphone-connected hearing aids confer additional benefits above and beyond those already provided by traditional hearing aids.

2. DIRECT-TO-CONSUMER (DTC) AMPLIFICATION PRODUCTS

The Over-the-Counter (OTC) Hearing Aid Act, which is part of the US Food and Drug Administration Reauthorization Act of 2017 [29], affords adults (i.e., ≥ 18 years) with mild to moderate hearing loss “access” to self-testing of hearing sensitivity, in addition to the option to self-fit and purchase affordable FDA-approved hearing aids directly from a supplier. It should be noted that the impaired listener is not required to consult with a licensed professional, hence, the term OTC. The guidelines governing “access” were expected to be published in the first quarter of 2020 [30]. Presently, there is a category of amplification devices that are available for purchase without supervision of a professional, referred to as personal sound amplification products (PSAPs). PSAPs differ from OTCs in that they: (i) are not FDA-approved, and (ii) are designed to accentuate listening in certain environments (e.g., bird watching, listening to a lecture with a distant speaker). Consequently, unlike the forthcoming category of OTC hearing aids, PSAPs cannot be marketed as devices that help individuals overcome hearing loss.

Despite their strict FDA regulation, PSAPs have become one of the main alternative amplification devices to traditional hearing aids, especially when considering barriers surrounding affordability of and accessibility to hearing healthcare. Previous studies assessing PSAPs have investigated their electroacoustic characteristics, speech-in-noise performance, as well as self-reported benefit and satisfaction. Compared to traditional hearing aids, low-priced PSAPs provide varying degrees of performance. In most cases, PSAPs electroacoustic performance fail to meet prescribed target gains for age-related, sloping hearing losses [31-35]. Specifically, PSAP devices and traditional hearing aids that retail for *less* than \$150 and \$500 per unit, respectively, tend to yield unacceptable levels of equivalent input noise (EIN) and total harmonic distortion based on ANSI standards for traditional hearing aids [31]. These same, economically priced devices provide insufficient high-frequency amplification and too much low-frequency amplification for moderate degrees of hearing losses relative to a prescriptive target. In comparison, higher priced PSAPs (> \$150 per unit) perform closer to a traditional, more expensive hearing aid (> \$1,000 per unit), allowing for prescribed gain targets to be met for most mild to moderate hearing losses [31,32,36].

Studies evaluating speech-in-noise performance and self-reported benefit/satisfaction also show similar results [32,37,38]. Reed and colleagues [32], for example, compared speech understanding in noise for a hearing aid and five PSAPs (four “premium”, one “economy”). Results revealed similar speech understanding performance between the hearing aid and the three most expensive PSAPs (i.e., retailing at prices $\geq$ \$299.99). Speech understanding performance declined for the two, lower priced PSAPs. Specifically, speech understanding performance with a PSAP retailing at \$269.99 was reduced compared to the traditional

hearing aid and three, more expensive PSAPS. The lowest price PSAP, retailing at \$29.99, significantly degraded speech understanding ability compared to all other amplification products. It should be noted that, in the studies cited, smartphone connectivity was not utilized.

Recently, Almufarrij et al [39] undertook a study that included a range of PSAPs, including those that could be customized via smartphone apps. Namely, the authors' assessed 28 PSAPs that could be purchased online for less than £400 (approximately \$500). The electroacoustic performance, the ability to match gain and slope targets, as well as cosmetic appearance and willingness to wear, was measured for each PSAP and compared to a popular hearing aid provided free-of-charge by the UK NHS (Oticon Spirit Zest). Similar to existing research [31,32,36], the authors found that higher priced PSAPs were associated with better electroacoustic characteristics, match to target gain/slope, cosmetic acceptability and willingness to wear. It was also noted that PSAPs that could be customised via an accompanying smartphone app performed better than other devices that could not, although some of these devices could produce uncomfortably loud sounds and all had low cosmetic appeal ratings.

In sum, currently available evidence indicates that the quality of PSAPs, and the resulting performance, are associated with purchase price. In addition, the availability of user-adjusted controls via a smartphone app appear to improve frequency-gain usage and overall speech intelligibility to a level that is comparable to traditional hearing aids. As such, PSAPs could serve as an accessible, lower-cost amplification alternative for individuals who cannot afford or do not wish to pay the high "out-of-pocket" costs associated with traditional hearing healthcare services.

3. SMARTPHONE-BASED HEARING AID APPLICATIONS

The rise of hearing aid apps operating on a smartphone, that can be coupled to the user via wired or wireless earphones, arguably provides a potentially affordable and accessible alternative to traditional hearing aids. In one of the first studies assessing the utility of smartphone-based hearing aid apps, Amlani et al. [40] recruited 18 adults (50-90 years) with mild to moderate hearing loss and compared a traditional hearing aid with two apps (Ears; Microphone). The output of the earphones was transmitted to the user by means of a hard-wired, in-ear headphone with an inline microphone. The headphone coupled to the audio jack of the smartphone and the inline microphone served as the input transducer. In terms of electroacoustic characteristics, the maximum power output was significantly higher for both smartphone apps relative to the traditional hearing aid. However, although the full-on gain was lower for the Microphone app, there was no difference between the Ears app and traditional hearing aids. In addition, speech-in-noise perception, as well as self-reported benefit and satisfaction, were all comparable across all apps and devices studied. Thus, these results suggested that smartphone hearing aid apps could be a viable alternative to traditional hearing aids.

In a further study, Maidment and colleagues [41,42] examined the everyday experiences of existing hearing aid users (N=20) with mild to moderate hearing loss toward a range of connected hearing devices, including a freely available smartphone hearing aid app (Petralex). These authors compared smartphone-connected hearing aids that were individually programmed to the patients' prescribed target by an audiologist, with two other self-fitted devices: (i) an in-the-ear PSAP, and (ii) the Petralex app used with either wired earphones or a wireless hearable in a two-week field study. Results from patient-reported

outcome measures showed that use, benefit, satisfaction and residual disability for smartphone-connected hearing aids were all significantly better relative to all other devices trialled. However, the Petralex app coupled to wired earphones was also rated favourably, an outcome that could be attributed to user's ability to adjust the volume and frequency response in any listening situation.

In 2019, De Sousa and colleagues [43] investigated electroacoustic and self-reported performance in five normal hearing ($PTA_{0.5-4kHz} \leq 15$ dB HL) listeners across four apps (Petralex; Super Ear, Earshot, Hearing Aid Master) available on Android (Google Play) and Apple (App Store) operating systems. The latency of the amplified signal was compared across three Android smartphones and one iPhone using wired and wireless earphones. The shortest latencies were found across all apps when used on an iPhone (19-24ms) compared to an Android smartphone (45-235ms). In addition, the wired earphones (20-58ms) had much shorter latencies than the wireless earphones (145-580ms). The authors also evaluated subjective listening experience of the Petralex app, which had the best electroacoustic performance in terms of latency and speech-in-noise performance relative to the other apps studied. Most participants (4 out of 5) reported that conversations were “*easy to follow*” while using the app. Nevertheless, all participants stated that they would prefer to use a hearing aid if they had hearing loss, and commented that their own voice/environmental sounds were too loud or echoed.

A recent 2020 study has also compared a smartphone-based hearing aid app (Jacoti ListenApp) with three different brands of in-the-ear earphones (Apple EarPods; BlueEverBlue, Model 1200; Sennheiser IE 60) [44] in 12 listeners with high-frequency mild-to-moderate sensorineural hearing loss. These authors found that speech-in-noise

performance, as well as subjective ratings of sound quality/clarity and degree of mental effort, were significantly better when the app was used with the BlueEverBlue and Sennheiser earphones compared to an unaided, no earphones condition. In comparison, the Apple EarPods were no better than unaided across all measures employed, which the authors attributed to poorer electroacoustic characteristics.

The available evidence assessing smartphone hearing aid apps suggest that this connected technology may be a suitable alternative to hearing aids that can improve access to amplification. Even so, caution should be exercised given that there is variation in performance across apps, operating systems (iPhone or Android) and headphones used. Given that smartphone technologies and hearing aid apps will continue to advance, it is likely that further research will be necessary.

DISCUSSION

In the following section, we share evidence-based viewpoints of connected technologies towards service delivery in hearing healthcare, as well as trends in professional acceptance towards this technology.

Smartphone Technology and Hearing Healthcare Service Delivery

(Re)Shaping Health Behaviour

In recent years, the degree to which smartphone technology can reduce barriers to the adoption of amplification has been evaluated. In the Amlani et al [40] study mentioned previously, for instance, the subjective performance (i.e., benefit and satisfaction) of two smartphone hearing aid apps was compared to the performance of a traditional hearing aid for a group of 18 inexperienced listeners with mild-to-moderate hearing loss under laboratory

conditions. The group of participants for the study had previously elected against a trial period with amplification. Findings indicated that the smartphone hearing aid apps improved awareness towards the rehabilitative process and provided an opportunity to experience the positive benefits of amplification in improving communication abilities. Findings also revealed that users viewed the smartphone hearing aid apps as a starter (or “gate-way”) solution to overcoming their hearing difficulties, which might lead to take-up of hearing aids in the future.

In support of this latter finding, Amlani et al [45] assessed whether short-term experience with a smartphone hearing aid app positively improved patient attitude towards amplification uptake and the listener’s perception towards their hearing impairment. Two groups of 15 participants each were recruited for participation: (i) an experienced group of hearing aid users who had ceased utilizing their devices for >1 year prior to the study, and (ii) an inexperienced group of listeners who had not yet adopted any form of amplification. Participant attitudes were obtained using three surveys pre- and post-use of a smartphone hearing aid app in the real-world for four-weeks. Comparative outcomes were generalized to the Health Belief Model [46] in the context of perceived benefits (i.e., efficacy of an action to reduce risk) and barriers (i.e., tangible and psychological costs that inhibit compliance and adoption). Findings revealed that a short-term, real-world trial period with a smartphone hearing aid app modified attitudes of non-listeners and reluctant listeners towards hearing aids, as well as positively altered the perception of their reduced hearing sensitivity.

Similar to Amlani et al [45], Maidment et al [41,42] also examined the everyday experiences of existing hearing aid users (N=20) with mild-to-moderate hearing loss toward a range of smartphone-connected hearing devices using both quantitative and qualitative methods. In

terms of the qualitative aspects of the study, Maidment and colleagues [41] performed semi-structured interviews to gain in-depth insights into how participants used the smartphone-connected hearing devices during a two-week field study. Critically, the analysis of the qualitative data was underpinned by the Capability, Opportunity, Motivation – Behaviour (COM-B) model [47] and accompanying Theoretical Domains Framework [48]. The COM-B model is a contemporary, supra-theory of behaviour change that can enable researchers to better understand and describe health-related behaviours [49]; in this context, use of a smartphone-connected hearing device to manage hearing loss. Using this theoretical underpinning, Maidment et al [41] found that a key advantage facilitating use and adherence of all smartphone-connected hearing devices was the ability to make fine-tune adjustments via an app (Capability). Participants also commented that smartphone-connected devices could address issues surrounding stigma, as smartphones are ubiquitous in everyday life (Opportunity). In addition, the ability to adjust the gain and frequency response via an app made participants feel a sense of empowerment that they were in more control of their hearing loss (Motivation). Consequently, this study demonstrates the value of applying a contemporary model of health behaviour change to identify the key factors that influence device use in the real-world.

The studies highlighted in this section provide support for the utility of using a theoretical underpinning to understand patient behaviour in the context of alternative hearing devices. According to the UK Medical Research Council [50], such approaches not only provide important insights into how complex healthcare interventions operate, but can also be used to refine the design of future, high-quality research, such as randomised controlled trials.

Professional Position Towards Technology Application

In addition to assessing the patient's perspective, studies have also assessed the attitudes of hearing healthcare professionals toward the potential implementation of smartphone-connected hearing aids into clinical practice [20,51]. In a quantitative survey of US-based audiologists, Kimball and colleagues [20] found that clinicians: (i) were highly supportive of the integration of smartphone-connected hearing aids in adult aural rehabilitation, and (ii) advocated for the use of smartphone apps by patients to make fine-tune adjustments and personalise their amplification settings, but were less supportive of allowing patients to make permanent changes.

A similar pattern of results has been found in a UK-based online Delphi survey [51]—a formalised methodology that seeks consensus amongst a panel of experts. Namely, Olson et al [51] assessed the perspectives of hearing healthcare professionals working in either the independent sector or the NHS toward new and emerging hearing devices, including connected technologies. Respondents agreed that appropriate candidates for new and emerging devices should only include adults who report communication difficulties, that have sufficient digital literacy to use smartphone technologies and no medical contraindications. Survey respondents shared ambivalence concerning whether new and emerging devices should be provided via the Internet or from a non-audiological healthcare provider. While it was agreed that DTC service delivery models might improve accessibility, there were concerns about patient's ability to assess their hearing loss accurately, as well as delays they might experience in the treatment of other, more serious medical conditions.

Patient Self-fitting and Professional Autonomy

For the provider, smartphone-connectivity—whether coupled to a hearing aid or a smartphone-based hearing aid app—could be viewed as a threat to professional autonomy [52]. This threat stems from a paradigm shift in which emerging technologies permit greater interaction and adjustment by the patient in their everyday lives. This contrasts with the historical, real-ear-measurement-based approach to matching a prescriptive target undertaken by a hearing healthcare professional.

To date, the listener's ability to self-fit hearing aid parameters continues to evolve, with outcomes based primarily on the methodology permitted to the user. One such methodology involves the user selecting differences in hearing-aid parameters using pre-determined, frequency-gain modifications called “presets”. The success of this approach depends on how well the presets match the user-characteristics for which the device was intended (e.g., sloping mild-to-moderate loss). In a study by Humes and colleagues [53], impaired listeners (n=153) selected from among three identical hearing aids, each having a different frequency-gain preset. After a one-month trial period, performance with the selected preset (n = 50) was found to be equivalent in objective and subjective test measures to performance obtained in another group of listeners (n = 53) whose devices had been fit by a professional using ‘audiology best practice’ procedures (i.e. a real-ear-measurement-based approach).

By comparison, Leavitt et al [54] fitted the same hearing aid professionally versus those fitted with a single preset option (i.e. the highest gain preset reported in the Humes et al study [53]). In Leavitt et al study, the authors' found that performance was superior for hearing aids fitted by a hearing healthcare professional compared to the single preset option provided to the participant. The study design differences potentially provide an explanation for the

discrepancies in participant outcomes observed between the Humes et al [53] and Leavitt et al [54] studies. Thus, the ability of a listener to self-fit a hearing aid requires additional examination.

A second, and arguably more complex, methodology affords the user control over the electroacoustic parameters. Such an approach would allow the user to control of broad-band, low- and high-frequency gain, and potentially overall volume. Recent laboratory [38] and field [55] studies have shown that differences are negligible when listeners are permitted ~~with the opportunity~~ to self-adjust the degree of amplification compared to amplification set by a professional, ~~differences are negligible~~. In addition, providing the listener with adjustment controls can yield successful performance outcomes (e.g. audibility, sound quality, benefit, satisfaction), in addition to accommodating a wider range of losses compared to the self-fit option that utilizes presets.

When coupled with qualitative findings [22], the quantitative studies outlined in this section provide evidence to suggest that the perception of hearing healthcare professionals towards implementing smartphone-connected hearing devices in their clinical practices is mixed. On the one hand, these devices provide greater patient autonomy through increased electroacoustic flexibility, whilst, on the other hand, there is concern toward clinical autonomy for audiologists and hearing instrument dispensers in their quest to develop a patient-centered relationship. To complicate matters, the recent global pandemic has markedly impacted the ability of providers to deliver diagnostic and treatment services to listeners exhibiting hearing difficulties. As we look to the future, the recent experiences with COVID-19 have shed light on the critical need for refined diagnostic and treatment protocols. For the latter, DTC amplification products and smartphone hearing aid apps could serve as a

stop-gap treatment option, affording listeners the opportunity to utilize their smartphones as sound amplifiers when traditional, clinic-based treatment options are inaccessible.

SUMMARY AND CONCLUSIONS

In this paper, we have provided an overview of the current evidence assessing a range of connected technologies for hearing loss, including smartphone-connected hearing aids, DTC amplification products and smartphone hearing aid apps. To date, research in this area suggests that these technologies have the potential to transform hearing healthcare service delivery that moves beyond the traditional, clinic-based model, toward a more patient-centered approach. The evidence we have reviewed strongly supports the assertion that connected hearing technologies could improve accessibility to and affordability of amplification. Nevertheless, a degree of caution needs to be exercised given that evidence is by no means conclusive as to whether connected technologies are a clinically effective alternative to traditional hearing aids in adults living with hearing loss. However, as stated previously, a smartphone-based amplifying solution has the potential to provide listeners experiencing hearing difficulty with a treatment option to improve their ability communicate, which may be particularly beneficial due to the limitations imposed by the global pandemic on hearing healthcare service delivery. Optimistically, the potential aided benefit and perceived satisfaction received by a listener utilizing a smartphone device to improve their quality of life also has the potential to enhance the patient journey towards adoption of traditional hearing aids.

We acknowledge that in this review we have not touched upon whether these connected technologies, which are mainly operated using smartphones, are an accessible option for the typical first-time hearing aid user age group. A number of studies outlined have found that

there is a general view, or assumption, that these devices might be better suited to and are more ubiquitous in a younger demographic [e.g. 41,51,56]. Despite this assertion, it should be noted that approximately 5.2 billion people worldwide own a mobile device, 60% of which are smartphones [57]. The proportion of older adults in the typical first-time hearing aid user age group that own a mobile device has also continued to grow exponentially; in the US, the proportion of 50–64 year olds that own a smartphone has risen from 34% in 2012 to 79% in 2019 [58]. What this suggests is that, against initial preconceptions, smartphone-connected technologies may be a suitable amplification alternative to traditional hearing aids for older adults.

Taken together, therefore, as advancements in self-adjustable technology emerge, and as further research ~~sheds light on the importance of~~ supports utilizing amplification ~~early in the treatment to delay the onset of associated comorbidities, such as cognitive impairments and dementia~~ [59] ~~Furthermore, considering the global pandemic,~~ the profession is now compelled to reassess its scope of practice with respect towards treating people living with hearing loss. This change in focus is further magnified by the changes in service delivery during a global pandemic. On this basis, emerging technologies should be viewed as having the potential to enable new and improved service delivery models that increase accessibility and affordability to the patient, and have the potential to increase autonomy and profitability to the provider. Clearly, the impact of connected technology on patients, as well as the hearing healthcare profession more generally, will be a topic of growing economic and public health interest given the recent impact of COVID-19.

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