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Hearing Aid Accompanying Smartphone Apps in Hearing Healthcare. A Systematic Review

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Abstract
Hearing Healthcare is in the midst of a paradigm shift due to increasing technologies and a changing patient generation. Hearing aids come up with more and more functions that have become possible due to the connection with smartphones and already a mayor part of the current patients is familiar using them via mobile applications. These apps are not only the interface between the hearing aids and the user, but also between the user and its Hearing Care Professional. This Systematic Review, based on the PRISMA model, analyzed 1712 articles with the aim to filter them concerning to hearing aid accompanying smartphone apps. A total of ten articles were included in the qualitative synthesis because they contribute to the research field of those smartphone applications in terms of classification and assessment, practical application or implementation in the fitting process. It could be concluded, that engaging the patients more into the process of hearing aid fitting via smartphone apps, will lead to better hearing aid outcomes in terms of satisfaction and benefits, usage and hearing quality.

Keywords: Hearing Aid; Smartphone; App; Medical Informatics; e-Health

Introduction

Hearing loss affects the quality of life much more than initially assumed. The largest number of complaints are problems in recognizing speech, especially in noisy areas. That communicative disability affects both, hearing impaired people and people in their environment. In addition, the ability to detect, locate and identify sounds quickly and reliably, is also affected. This together leads to a reduction in the quality of life, related to isolation, reduced social activity, a feeling of being excluded and increased symptoms of depression [1]. It is estimated that in Europe, about 30% of men and 20% of women aged 70 years, have a hearing loss >30 dB HL. By the age of 80, this figure is already 55% of men and 45% of women [2]. To compensate for these limitations, hearing aids can be fitted by an audiologist [3]. These devices have a long history. From the ear trumpet as a sound collector to transistors, microprocessors and digital signal processing [4], the development of hearing aids has been impressive and has delivered more and more benefits to its users. According to the U.S. Food and Drug Administration, they are sound amplifying devices, designed to aid people who have a hearing impairment. The devices – independent of the model- share similar electronic components, including at least one microphone, an amplifier, that makes the sound louder and a loudspeaker, that delivers the amplified sound into the ear canal. They can be differentiated by the design, the

technology or by special features [5]. Equipped with the latest Bluetooth technology [6], hearing aids can be connected with the user´s smartphone and fittings can be changed over mobile apps, which enable the Hearing Care Professional access to the devices. These apps also allow the user itself to use the smartphone as a remote control with several options to change the hearing aid´s fittings in a limited way [7]. Especially the possibilities for hearing aid specialists bring the aspect of Tele – Audiology on a new level, which is defined according to Northern, as the use of electronic information and telecommunications technologies to support remote and distance clinical hearing healthcare [8]. Although this form of patient care was previously only intended to compensate the lack of audiologists in rural areas, it is now part of the paradigm shift that exists based on changing patient demographics and its different demands[9]. Due to the rapidly aging population and the increasing use of smartphones[10], it can be assumed that there will be much more research and development in the field of mobile applications for hearing aids in the future, which will take this paradigm shift into account. In addition to these points, the use of smartphone apps by the user and the associated higher level of engagement might offer more benefits. One of the biggest problems is that hearing aids are not worn as often as they should. The most common cited reasons for this behavior are negative experiences with sound, speech understanding, and annoying background noise [11]. It is conceivable that these issues can be improved through the intervention of the user via an app. This paper therefore examines how hearing aid accompanying smartphone apps - thus that kind of apps that hearing aid manufacturers have developed specifically for the use in combination with their hearing aids - affect hearing aid outcomes and the benefits they create for Hearing Care Professionals and patients in the context of a systematic review. It aims to encourage audiologists to integrate smartphone apps into the fitting process.

Material and Method

The PRISMA scheme was applied for the Systematic Review [12], which is presented in Figure 1. An overview of the research framework can be found in Table 1.

Table 1. Review protocol according to Wohllebe [13]

Review question	"How does the Use of Hearing Aid Accompanying Smartphone – Apps affect Hearing Aid Outcomes?"
Literature search	*Sources*: Science Direct, google scholar and PubMed
	Search Term: („hearing aid" OR „hearing healthcare" OR "hearing care" OR "hearing impairment" OR "hearing device") AND („app" OR „smartphone" OR „e-health" OR „m-health" OR „tele-audiology" OR „remote" OR "telemedicine" OR "telehealth" OR "mobile phone")
Filter criteria	*Type of work: All type of publications* *Years:* 2005 - 2020
Exclusions	*By title*: Examination of topics in a broader sense, exclusion of publications especially related to traditional Tele-Audiology and remote issues
	By abstract: Exclusion of articles not related to the combination hearing aid and mobile applications
Evaluation	*Full-text assessment*: Inclusion of those articles which are engaged with hearing-aid accompanying smartphone-apps

The search for relevant records was conducted in the mentioned databases on May 20, 2020. The keywords were intended to cover the combination of hearing aids and apps. Due to the fact that today's Tele-Audiology is almost exclusively app-based, the term was also included, as well as the key word remote, which stands in the broadest sense for all processes from a distance. This include remote fittings of Hearing Healthcare Professionals, as well as the user´s possibility of changing the hearing aid´s settings in the context of a remote control.

The inclusion criteria were as follows: Hearing aid accompanying smartphone apps, which are used in combination with the corresponding hearing aids

The exclusion criteria were as follows:

- Pediatric audiology
- Cochlear Implants and implants in general
- Results about stand - alone audiological mobile apps, without any hearing aid relation
- Over the Counter products or any kind of self – fitting devices

Results

The number retrieved materials according with the search databases during the defined period are presented in Table 2.

Table 2. Initial results of the literature search

Search Term	Science Direct	Google Scholar	PubMed	Results after Removing duplicates
(„hearing aid" OR „hearing healthcare" OR "hearing care" OR "hearing impairment" OR "hearing device") AND („app" OR „smartphone" OR „e-health" OR „m-health" OR „tele-audiology" OR „remote" OR "telemedicine" OR "telehealth" OR "mobile phone")	612	933	167	881

Two records were excluded which, although they fitted the subject matter exactly, were not published in a scientific context. Explicitly mentioned examples of this are the following works:

- Signia TeleCare Facilitates Improvements in Hearing Aid Fitting Outcomes [14]
- User Engagement with Signia TeleCare: A Way to Facilitate Hearing Aid Acceptance [15]

In this Systematic Review there has been no type of publication excluded due to its type.

According to the mentioned Prisma Flow Chart, the following search steps were conducted:

- Identification. In that step, the duplicates were removed with the result that 881 of 1712 records remained in the review process.
- Screening. The titles of these records were screened and 567 removed due to a missing relation to the research topic. Most of these removed records were in the field of traditional Tele – Audiology or in several hearing healthcare related sectors. Based on the overlap of audiology and smartphone technologies, various records from the field of computer science were found. Those were also rejected due to the lack of connection to the research question. After this step in the review process, 246 publications remained in the database and advanced to the next stage. The abstracts of the records mentioned were read and 178 of them were also sorted out due to irrelevance to the research question.
- Eligibility. Finally, the remaining 68 records were read in full and evaluated for their use in the Systematic Revue. The reason for excluding 58 of them were different. As in the screening phase, some had a wrong setting, i.e. the combination of apps and hearing aids was not given, or the paper focused on self-fitting devices. Afterwards, the references of the records were screened completely to identify additional records. No further ones were discovered and accordingly noted in the Identification step of the Prism Flow Chart (Figure 1).
- Included. Ten of them were then assigned to the qualitative synthesis and consequently listed with their scientific results (Table 3). They were grouped due to its characteristic into the following sections: i) Classification and Assessment ii) Practical Application iii) Integration into the fitting process and further chronologically listed. If several records appeared in the same year, they were arranged according to the first letter of the main author.

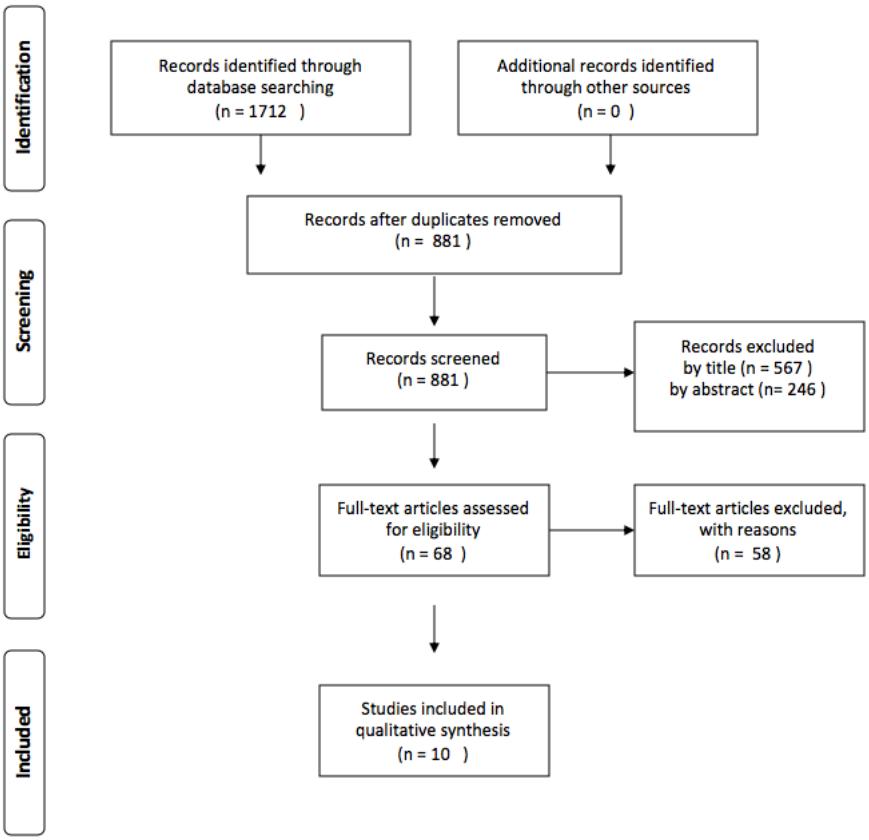

Figure 1. Prisma flow chart

The particularities of each study included in the study are presented in Table 3.

Table 3. Summary of the review's results

Author [ref]	Aim	Methods	Outcomes
Classification and Assessment			
1. Offiah et al. 2014 [16]	Investigation of the connection between hearing aids and a smartphone app in terms of algorithms with the aim of a better differentiation of speech and noise.	Computer based app examination of ten different apps and evaluation with a Cost- Utility Analysis (CUA) as a general framework.	The tested three hearing aid accompanying apps leave a lot of room for improvement and aimed a relatively low score in the CUA. This is largely due to their low scoring in- and output support
2. Paglialonga et al. 2015 [17]	Review of available smartphone apps in Hearing Healthcare	Reviewing available apps in the field of hearing healthcare on the Apple Store, Google Play and the Windows Phone Store.	200 Hearing Healthcare related apps were found in the App Stores and grouped into five different categories.
3. Paglialonga et al. 2015 [18]	Evaluation of Apps in Hearing Healthcare in regarding of services, price and the need for additional external devices	Evaluation of available smartphone apps focused on service offered by the app, the apps price and the need for additional equipment or devices.	203 apps in hearing healthcare are available for hearing professionals and people with hearing problems. Regarding to hearing aid accompanying smartphone apps it can be

Author [ref]	Aim	Methods		Outcomes
				determined, that they can increase mutual interactions between patients and audiologists and increase patient´s satisfaction.
4. Tognola et al. 2015 [19]	Developing of an e-health model for people with hearing loss, to take the digital transformation into account	Analysis of four target groups of people with hearing loss with several demands concerning hearing aid usage.		An ehealth4hearing paradigm was defined, which is delivering a new patient – centered model where people can use e-health tools in various steps of the patient journey in hearing healthcare. Due to the resulting higher engagement, they become an active participant in the fitting process.
5. Paglialonga et al. 2017 [20]	Developing of an user support tool for a more informed adoption of health apps	The research was done in three steps from outlining a descriptive method to characterize hearing healthcare apps, visualizing it and finally proposing an automated approach, able to extract meaningful information about apps directly from the web.		Creation of the ALFA4hearing model, which classifies hearing aid apps in hearing healthcare in regarding of promoters, services, implementation, users and descriptive information.
Practical Application				
6. Johansen et al. 2017 [21]	Inference of the optimal hearing aid settings, based on user adjustments in real life situations over an app	The participants had the opportunity to change the hearing aid´s setting with the app. The setting´s changes were assessed depending of the day of the week.	N = 6 Ø Age: 61,8 Mild-severe hearing losses	Different hearing aid settings regarding to program changing and adjusted volume depending of the day of the week. The inclusion of individual behavior patterns in the settings can have a positive influence on the use of the devices.
7. Habib et al. 2019 [22]	Identifying the user´s preferences and usability and the benefits of using an accompanying smartphone app	Participants were equipped binaurally with hearing aids and the accompanying smartphone app. After seven weeks, the app usage was evaluated and compared to a control group.	N = 30 Ø Age: 68 Ø Hearing loss: 38 dB HL	Subjects had significant improvements due to the usage of the smartphone app, especially in hearing aid benefit and satisfaction.
8. Pasta et al. 2019 [23]	Finding the optimal hearing aid settings in a defined context and situation	Comparison of the individualized hearing aid settings created by the patient´s app usage with those from traditional clinic workflows.	N = 7 Ø Age: 58,3 Mild – moderately severe hearing losses	Five out of six participants preferred the self -adjusted settings with the app compared to the traditional clinic workflow.

Author [ref]	Aim	Methods		Outcomes
9. Convery et al. 2020 [24]	Analysis of the effect of using an accompanying smartphone apps in regarding of patients / audiologist communication and hearing aid outcomes	Participants were divided into an intervention and a control group. The intervention group used an app and was attended over it digitally. The control group was attended traditionally.	N = 30 Ø Age: 67 Ø Hearing Loss: 45dB HL	Using the app has no detrimental effect on hearing aid outcomes and can improve the communication between patient / audiologist
Integration into the fitting process				
10. Kimball et al. 2018 [25]	Investigation of the willingness to integrate smartphones into the fitting process among audiologists	Questionnaire based survey among 258 audiologists in the USA		A mayor part of the audiologists is open to integrate smartphones into the fitting process, especially those with more years of experience.

Discussion

Classification and Assessment

Offiah et al. (2014) investigated the connection between hearing aid and smartphone mobile applications regarding to different algorithms with the aim of a better differentiation of speech and noise. The study is based on the assumption that due to the higher computing power and the more complex operating system of smartphones, better speech understanding with hearing aids can be achieved by using the smartphone as an external microphone. Using the app, the individual input signals are calculated or differentiated and then transmitted back to the hearing aids for output. In this study different hearing healthcare apps were tested, three of them from hearing aid manufacturers. These apps were evaluated for signal input and output, the possible hearing profiles, the settings per ear, the possibility of hearing measurements and the availability on the different platforms and finally weighted with a combined value. When evaluating the study data, the authors came to the conclusion that although some manufacturers have smartphone apps, they still leave a lot of room for improvement, especially in the areas of signal input and binaural support [16]. It is noteworthy that this study focuses more on the electrotechnical than on the audiological component, which differentiated that results a bit from the rest in that category. Since most of the signal processing takes place in the hearing aid and not on the smartphone, the relatively poor performance of the hearing aid accompanying apps regarding to the signal input and output is also understandable. This fact limits the interpretation of the study results a bit.

Paglialonga et al. (2015) reviewed the available smartphone apps in Hearing Healthcare. Therefor they searched in the Apple Store, the Android Market in Google Play and the Windows Phone store for related applications. In November 2014 they found a total of 200 relevant apps in this search, which they divided into five different categories. These categories were i) education & information ii) hearing testing iii) rehabilitation iv) sound enhancement v) assistive tools. The category "sound enhancement", which accounted for 28% of the relevant apps, includes the mobile applications of the hearing aid manufacturers. With those, it is possible to support the hearing aid use (e.g., system control, support to hearing aid selection, ratings of listening experience or consumer engagement services) as well as personal enhancement tools. Hearing aids users can use these apps to personalize the device´s settings in real time to limit the need for face to face appointments. The authors concluded that there is a paradigm shift in Hearing Healthcare from the traditional hospital-centric model to a more flexible model where the patient is more empowered and involved in the fitting process and the usage of mobile applications plays therefore a major role [17]. The importance in

practice seems to be clear. In a large number of Hearing Healthcare related apps, it is difficult for users - especially older ones - to find their way around. A grouping of the available applications as suggested, could lead to a significant simplification and clarity in practical use.

With a similar approach, Paglialonga et.al. (2015) published another paper in the field of apps in hearing science and care. Their aim was to evaluate the available apps according to the services, or combination of services, the price and the need for additional external devices. In this study, they classified the 203 found apps in four categories, i) screening and assessment ii)intervention and rehabilitation iii) education and information and iii)assistive tools. The applications of the hearing aid manufacturers belong to the group of intervention and rehabilitation, which makes up 52% of the found apps. The 203 apps were analyzed according to the price and divided into five groups, from free to >15 euros. The hearing aid manufacturers' mobile applications were all free of charge. The authors concluded that the use of hearing aid manufacturer apps can improve mutual interactions between patients and audiologists and increase patient satisfaction and benefits. As a drawback they mentioned, that the usage of this technology may temp patients to overlook or greatly reduce the contact and exchanges with their audiologist [18]. In this argument, the actual use of apps is probably the decisive point. In particular, one of the main functions - modern tele-audiology - can be used to provide more up-to-date customer care. Preliminary studies from classic tele-audiology, such as the already mentioned by Gladden et al. [9], show that this form of patient care has no disadvantages compared to face to face treatments. Moreover, since the user himself has only limited access to the settings [7], these concerns can be dispelled by clear workflows, such as frequent service appointments in the clinic.

Tognola et al. (2015) described in their work the silent and disrupting revolution in hearing health care practice, based to the increasing usage of e - health methods and technologies, in particular mobile smartphone applications. Their goal was to develop a new "ehealth4hearing" model and to define the associated boundaries and rules. In this paper, they tried to give an answer, what could be envisaged with that model, how it would contribute to patient – centeredness, patient empowerment and patient – caregiver relationships. Further, they highlighted the differences between the traditional health care services and the "ehealth4hearing" model. A total of four target groups of people with hearing loss were defined, differentiated by the type of services needed to manage their impairment as well as the various perceived needs. They found that the target group, who already require amplification because of their hearing loss, has the demand to be able to change the settings of the hearing instruments quickly and flexibly to tailor them to their needs. The advantage of the "ehealth4hearing" model is that this target group can implement their wishes themselves via a mobile app, i.e. they can use their smartphone as a remote control. Remote consultations and individual engagement services, which are also conducted by the several apps, engage the patient to become an active participant in the hearing aid selection process. This is, so they concluded, a huge advantage compared to the traditional model [19]. Especially in the course of the generational changes of patients, this conclusion seems very plausible. Similar results about the advantages of remote treatments compared to the traditional way can be observed in the field of general medicine and can be used for comparisons with Hearing Healthcare[20].

Paglialonga et al. (2017) investigated several hearing healthcare related smartphone applications. The aim of their work was the development of user support tools for a more informed adoption of health apps. They created the ALFA 4 hearing model, which characterizes apps for hearing healthcare by using 29 features, grouped into five components. With this model, it is possible to classify hearing aid manufacturer apps regarding to promoters, services, implementation, users or descriptive information. The study showed the value of characterizing health apps features by extracting its meaningful information based on the large amount of information that can be found in the web [20].

At the category Classification and Assessment, it has to be noted that almost all relevant records were written with the participation of Paglialonga and Tognola. A number of commonalities could be identified. While Records 1, 2 ad 3 dealt with analyzing and categorizing the multitude of apps in hearing healthcare, Records 4 and 5 focused on the creation of models to simplify the use of the applications in terms of target groups and information. Another important conclusion of publications 2, 3 and 4 is that the active involvement of patients by using smartphone apps in the hearing aid fitting process, can lead to a higher customer satisfaction. It may make sense to perceive the hearing

aid user less as a patient and more as a consumer, with the consequence to engage him much more in the treatment [20]. The records of that category determine the theoretical and therefore descriptive part in the field of hearing aid accompanying smartphone apps with the aim to provide a good theoretical basis for the practical use of them.

Practical Application

Johansen et al. (2015) investigated in their study how a hearing aid is used throughout the day. Instead of simulating listening scenarios in a clinic, they had the aim to infer the optimal hearing aid settings based on how the user adjusts programs or volume in changing real life situations. For the study, they selected six experienced hearing aid users with mild to severe hearing losses. All of them used an iPhone 4s or newer with Bluetooth 4.0 and were fitted binaurally with two Oticon OPN hearing aids and the corresponding Oticon iPhone app. Four different hearing programs were set up and the use of those was examined according to the day of the week and the time of day. In addition, the user intervention on the amplification of the individual hearing programs was also analyzed. They found out, that volume and program interaction differed from Monday – Friday and the weekends and that these individual behavior patterns affected the usage of the devices. This outcome is of great relevance in the context of the frequency of use of hearing aids. As mentioned in the introduction, hearing aids are often not worn much as they should. The inclusion of these individual behavioral patterns in the hearing aid setting can therefore positively influence the use and thus reduce one of the biggest barriers in this area. The authors proposed, that rethinking hearing instruments as devices, that adaptively learn behavioral patterns based on user interaction, might provide a degree of personalization, that wouldn´t be possible due to a lack of audiologist´s resources. They recommend a new way of hearing aid fitting, connecting the hearing aids with the smartphone and the Internet to make them cloud connected devices. Finally, a paradigm shift is proposed, where the audiological best practice includes decisions making from user generated data reflecting everyday usage [21].

Due to technological and socio-demographic changes in Hearing Healthcare, Habib et al. (2019) conducted a study to evaluate the benefits of smartphone connected hearing aids and to identify the user´s preferences and usability in regarding of functionality of an accompanying smartphone app. Over a period of seven weeks, the smartphone connected hearing aids were tested by 30 test persons and evaluated for their use and benefits. Subjects, whether they were experienced or first - time hearing aid users, indicated that they had significant improvements in terms of social participation, hearing-related fatigue, quality of listening and hearing aid benefit and satisfaction due to the usage of the smartphone app. The authors concluded, that the tested app meets the needs of a typical NHS clinical sample of hearing aid users and due to empowering them to self – manage their hearing loss, the app provides them with a greater confidence, especially in challenging listening situations [22]. These study results also show that the use of smartphone apps in the context of hearing aid fitting offers great advantages for the user. Especially the optimization in the areas of speech understanding and sound - which are the most frequently cited reasons for not wearing hearing aids - can also have a positive effect on the wearing behavior.

Due to the fact, that hearing aids can potentially be complemented with smartphone apps, that model the sounding environment in order to find the optimal settings in a defined context and situation, Pasta et al. (2019) recommended a rethinking of hearing aids as context – aware recommender systems. They aimed to analyze the challenges in this process and addressed them by gathering the preferences of seven participants in real world listening environments. They fitted Oticon hearing aids and installed the corresponding mobile app, which enabled collecting data about the audiological preferences and the corresponding context. The test persons were given the opportunity to optimize noise reduction and directionality, brightness and soft gain in four different levels. In addition, each time they reported on their preferences, they specified about the environment they were, their motion state and their audiological intent. They sequentially optimized the three mentioned audiological parameters, which subsequentially were combined in a personalized device configuration. Finally, this configuration was compared against a configuration personalized in a standard clinical workflow and six out of seven participants preferred the device settings learned in

real world listening environments [23]. It is obvious that the inclusion of the daily hearing situation in the hearing aid settings is of great importance and therefore allows a more individualized fitting of the devices. The use of smartphone apps is here the interface in this process.

To analyze to what extent the use of smartphone apps in combination with hearing aids facilitates communication between audiologists and patients and influences hearing aid outcomes, Convery et al. (2020) conducted a study with 30 subjects. During the six-week study period, one group received regular face-to-face care, while the second group received tele audiological care via the GN Resound smartphone app. The results of the study were evaluated in terms of hearing aid outcomes, satisfaction and use. The authors came to the conclusion that care via the smartphone app had no detrimental effect on fitting results - at least in the short term and could enable patients to communicate remotely with their audiologists to seek and receive help with their hearing aid problems [24]. These results also confirm the results of the traditional Tele-Audiology studies that there are no audiological disadvantages [9].

The evaluation of the studies in this category yielded very relevant results for practice. Records 6,7 and 8 had partly similar study objectives and finally delivered similar conclusions. They set themselves the goal of individualizing the hearing aid settings by the patient using a smartphone app. These individualizations led to an increase in patient satisfaction in Records 7 and 8, in part also in direct comparison with the traditional clinic work- flow. It can be assumed that this increased patient satisfaction will also increase the wearing time of hearing aids, which is also confirmed by the outcomes of record 6.

Integration into the Fitting Process

To investigate the willingness to integrate smartphones into hearing aid fitting, Kimball et al. (2018) conducted a survey among 258 audiologists in the USA [25]. This survey focused on the use of the Phonak smartphone app and analyzed in ten items the extent to which audiologists would involve patients in the fitting process via smartphone. The key finding of that study was, that the audiologists generally expressed a high willingness to integrate the smartphone into patient care. Similar older papers in the context of traditional Tele – Audiology [26,27], confirmed that results years ago, using traditional Tele-Audiology tools. A surprising outcome was, that the audiologists with the least number of years of experience had more negative attitudes toward smartphone integration, than audiologists with comparatively more years of experience. The authors concluded, that due to further improvements of technologies, patients will take a greater role in hearing healthcare and audiologist will need to be prepared to adapt [25]. This trend will accelerate, especially with regard to generational changes [28] and the new patient´s – the Baby Boomer´s – demands [29].

Conclusion

This Systematic Review showed very clearly that the use of smartphone apps in the hearing aid fitting process can positively influence Hearing Aid Outcomes. It was found that the patient satisfaction is related with a greater involvement of patients through the use of apps and a higher degree of individualization of the device's settings. It can be concluded that these results lead to an increase in the wearing time of the devices. Especially with regard to further technical developments in the direction of artificial intelligence and a changing customer generation, the use of these applications will become even more important in the future. Furthermore, not only the audiological effects of using smartphone apps should be investigated, but also their influence on the relationship between Hearing Care Professional and patient.

List of abbreviations

NHS – National Health Service (UK)

Conflict of Interest

The author declares that he has no conflict of interest.

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