Do smartphone hearing aid apps work?

by Karina C. De Sousa; De Wet Swanepoel, PhD; Lina Motlagh-Zadeh, PhD; David R. Moore, PhD & Hermanus C. Myburgh, PhD

Ms. De Sousa is a doctoral student in audiology at the University of Pretoria (UP) in South Africa. Her work is focused on investigating smartphone-based speech-in-noise tests for accessible and affordable hearing health care.

Dr. Moore is the director of the Communication Sciences Research Center at Cincinnati Children's Hospital, a professor of otolaryngology and neuroscience at the University of Cincinnati, and a professor of auditory neuroscience at the University of Manchester.

Dr. Zadeh is a research associate in communication sciences and disorders (CSD) at the Cincinnati Children's Hospital. Her research interests include developing behavioral measures to assess the effects of basic and advanced auditory abilities on speech perception in noise, understanding the mechanisms underlying hidden hearing loss, and optimizing hearing care delivery.

Dr. Myburgh is the head of the Advanced Sensor Networks (ASN) research group at UP's department of electrical, electronic, and computer engineering. He's a co-inventor of several smartphone-based hearing assessment solutions, and a co-founder and scientific advisor to the hearX Group.

Dr. Swanepoel is a professor of audiology at UP and the editor-in-chief of the *International Journal of Audiology*. His research capitalizes on digital health technologies to explore, develop, and evaluate innovative hearing services for greater access and affordability. He is also a founder and scientific advisor to the hearX group.

Hearing aids are a central part of the management process for hearing loss in adults. Despite evidence supporting improved listening abilities and quality of life as a result of hearing aids[1], uptake remains poor. Persons with hearing loss typically only take action after an average of 6 to 12 years from initial identification of the loss[2,3]. Factors hindering help-seeking and hearing aid uptake are varied and include personal readiness, finances[4] and stigmatization[5]. Alternative amplification options within a consumer-driven service delivery model have the potential to increase choice and initial access to hearing care. Traditionally, a hearing aid is prescribed after evaluation by a licensed professional. The US Food and Drug Administration (FDA) published a nonbinding recommendation report no longer enforcing medical assessment before provision of amplification[6] which allows for alternative self-test diagnostics and hearing devices.

The ubiquitous nature of smartphones and the rise of hearing aid applications (apps) are promising widely accessible and affordable amplification alternatives to traditional hearing aids for certain persons[7,8]. Downloadable apps are appealing considering the widespread ownership of smartphones and mobile connectivity. Already, 61% of the global population are mobile internet users, with expected growth to 79% by 2025[9]. Amid rapid technological advancement, a large number of smartphone hearing aid apps are available. However, very limited evidence on performance and benefit compared to conventional hearing aids is available. One study investigated two smartphone hearing aid apps and showed comparable benefit to a conventional hearing aid for amplification and speech-in-noise improvement[7]. Due to constant developments in smartphone technology, and the number of hearing aid apps newly available, this study investigated electroacoustic and self-reported performance across a range of apps and smartphone manufacturers.

iStock/elenabs2

METHODS

The study received Institutional Board Approval from the Health Science Ethics Committee at the University of Pretoria, South Africa. Two investigators evaluated apps on both Google Play and Apple App stores according to the following criteria: Apps had to (i) be downloadable and function without active internet connection; (ii) be simple to use without specialist knowledge; (iii) function through inexpensive wired earbuds or headphones and (iv) produce reasonable quality sound as assessed through an informal listening check. Four apps on both Google Play and on iStore were selected for objective evaluation (Table 1). The apps were evaluated for 1) objective sound quality (latency and signal-to-noise ratio (SNR) improvement) and 2) subjective listening experience.

Table 1. Latency (milliseconds) from original sound source to output from wired earbuds among Android smartphones and applications.

	Huawei Mate 10 Pro	Samsung A3	Samsung S7
Petralex	160 ms	58 ms	45 ms
Super Ear	220 ms	230 ms	195 ms
Earshot	180 ms	245 ms	230 ms
Hearing Aid Master	215 ms	315 ms	235 ms

In terms of sound quality, the latency or time delay for amplified signals was measured across three Android operated smartphones and one Apple iPhone to evaluate the performance of the apps (Table 1). Latency was measured using a Rion NL-52 sound level meter and G.R.A.S 46AG-4 CCP occluded ear simulator, presented and recorded using Audacity® software (version 2.20). Click stimulus with one second between clicks was used to measure round-trip latency (in milliseconds) from the original sound source (loudspeaker) to output from manufacturer supplied wired Samsung earbuds. In addition, latency using the premium version of the *Petralex* app was measured between the wired earbuds and a set of wireless headphones (LG HBS with insert earbuds) for a Samsung S7 and the iPhone 6. In all instances the smartphones were placed 20 cm 0° azimuth from the loudspeaker. The smartphone apps were kept to default settings.

SNR improvement was measured using three higher end smartphones (Samsung S6, Samsung S7 and iPhone 6) using various hearing aid apps and their respective noise suppression or program options (Table 2). Spoken digit triplets (0 to 9 separated by 500 ms silence) were presented in speech weighted masking noise at 0 dB SNR with the noise energy and digit energy kept constant at 70 dB for all recordings. The presented sound was received via the embedded headset microphone and the smartphone output was recorded on a laptop computer via the artificial ear. Before SNR gains could be calculated, calibration across smartphones had to be done. To this end, the differences in noise energy, where no noise suppression was used, was calculated. These differences were used to calibrate the output of each smartphone/app-pair to 0 dB for no noise suppression. After calibration, the energy for each smartphone/app-pair was calculated for noise only, as well as for noise plus digits. This was done for no noise suppression as well as all other available noise suppression settings. The SNR gains achieved by the various noise suppression settings were calculated by subtracting the noise energy from the noise plus digits energy in each case.

Table 2. Latency (milliseconds) from original sound source to output from wired earbuds for iPhone 6 across applications.

Petralex	24 ms
Fennex	24 ms
Mobile Ears	20 ms
Super Hearing Aid	19 ms

For the listening evaluation five normal hearing ($PTA_{0.5\text{-}4kHz} \leq 15$ dB HL) participants were recruited from students at the University of Pretoria's Department of Speech-Language Pathology and Audiology, South Africa. Participants were asked to join in a one-on-one conversation with the investigator while using the free-trial version of the *Petralex* app (available on both Android and iOS) on an iPhone 6 coupled to wired earbuds. Participants were instructed to complete the incorporated self-hearing test on the application and adjust settings to their comfort. However, on the trial version, settings for noise suppression and own voice suppression options could not be activated. Afterward, participants were asked to participate in the conversation, which was maintained for 10 minutes (timed) by asking and answering questions. Two sets of questions (one for each conversation partner) on various topics (e.g. travel, work, music) were used to maintain the conversation. Afterwards, specific feedback related to the listening experience (Figure 1) was captured using a five-point Likert scale. In addition, participants could add additional feedback regarding their experience using the app.

RESULTS

Sound quality

In terms of latency all apps on iPhone 6 surpassed the three Android operated smartphones, with shorter latencies depending on the hearing aid app used (Table 1 and 2). The shortest latency was recorded for *Super Hearing Aid* using the iPhone 6. Latency varied for all hearing aid apps among Android operated smartphones. The shortest latency on Android was obtained using *Petralex* on the Samsung S7. Furthermore, there was a substantial difference in latency between wired and wireless earbuds. Wired earbuds had shorter latencies of 58 ms and 20 ms for the Samsung S7 and iPhone 6, respectively, as opposed to 580 ms and 145 ms using the wireless headset.

Some apps provided noise suppression or settings for different listening environments. SNR improvement (dB SNR) for the various apps with their respective settings are provided in Tables 3 and 4. *Fennex* on iPhone 6 produced the best SNR improvement of 18.1 dB SNR when noise reduction was activated. For Android, *Petralex* performed the best when set at full noise suppression, producing 3.9 dB SNR improvement. However, it was still considerably lower than the *Petralex* app on iPhone 6 showing 14.3 dB SNR improvement. In some instances, when no noise suppression or reduction strategies were set, SNRs became worse, for example using *Petralex* on the Samsung S6 (-2.1 dB), S7 (-1.6 dB) and iPhone 6 (-1 dB SNR). In general, apps with better sound quality performance (Android and iOS) were more expensive (Table 5).

Table 3. Signal-to-noise ratio improvement (dB SNR) across hearing aid applications, noise suppression or program settings for Android smartphone

		Samsung S6	Samsung S7
Petralex	No Noise Suppression	-2.11	-1.61
	¼ Noise Suppression	0.94	N/T
	Half Noise Suppression	1.43	
	¾ Noise Suppression	2.42	
	Full Noise Suppression	3.90	
Super Ear	Indoor	N/T	0.59
	Outdoor		0.57
Earshot	Default	N/T	0.48
Hearing Aid Master	Iron	N/T	0.55
	Gold		0.55

Table 4. Signal-to-noise ratio improvement (dB SNR) across hearing aid applications, noise suppression or program settings for iPhone 6

Petralex	No Noise Suppression	-1.02
	¼ Noise Suppression	2.25
	Half Noise Suppression	4.49
	¾ Noise Suppression	9.60
	Full Noise Suppression	14.33
Fennex	No Noise Reduction	-0.52
	Full Noise Reduction	18.11
	Dining No Noise Reduction	-1.22
	Dining Soft Noise Reduction	-1.05
	Meeting No Noise Reduction	0.18
	Meeting Advanced Noise Reduction	12.7

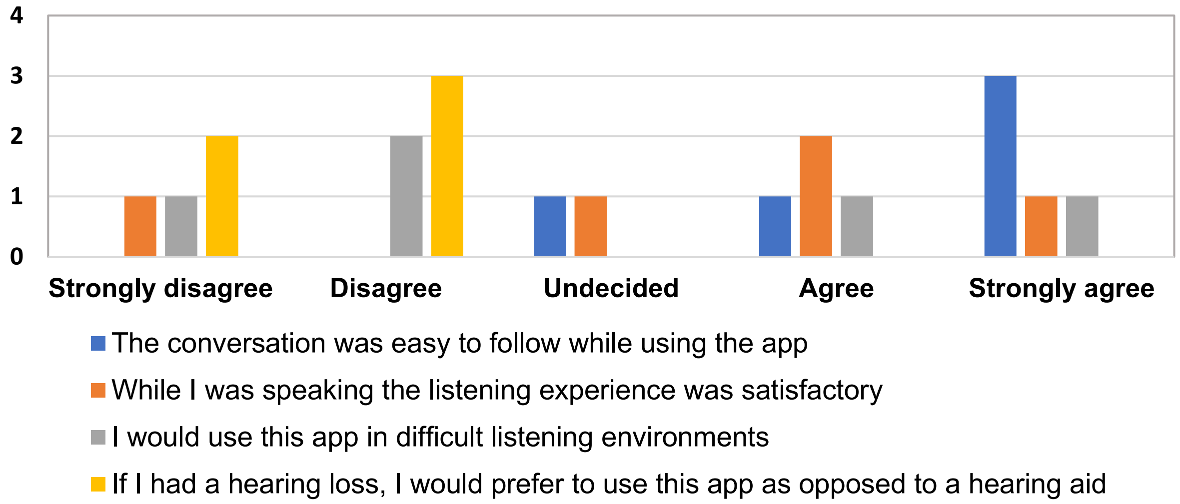
Mobile Ears	Default	1.28
Super Hearing Aid	Default	1.02
	Indoor	1.02
	Outdoor	0.84

Table 5. Cost of smartphone hearing aid apps for Android and iOS ($US)					
Android			**iOS**		
	Monthly subscription	**Once-off Annual cost**		**Monthly subscription**	**Once-off Annual cost**
Petralex	$9.44	$55.35	*Petralex*	$13.02	$63.82
Super Ear	Free	Free	*Fennex*	$4.99	$49.99
Earshot	Free	Free	*Mobile ears*	Free	Free
Hearing aid master	Free	Free	*Super hearing aid*	Free	Free

Subjective listening experience

Participants indicated whether they agreed or disagreed with five statements pertaining to their listening experience using the *Petralex* app (Figure 1) that had the best electroacoustic performance (Tables 1-4). The majority (4/5) either agreed or strongly agreed that the conversation was easy to follow while using the app. However, three participants indicated that they would not use the app in difficult listening environments, and all five participants indicated that they would prefer to use a hearing aid as opposed to the app (if they had a hearing loss). Where participants provided their own views on the app, three participants indicated that their own voice was either too loud or echoed, and that environmental sounds were over-amplified.

Figure 1. Views on the listening experience while using a smartphone hearing aid application (*n*=5)



DISCUSSION

Overall, apps on the iPhone 6 with wired earphones had the shortest latency and highest SNR improvement when using the *Fennex* and *Petralex* apps. Android phones had longer latencies and lower SNR improvement on all apps, and performance varied between devices. Research on tolerable processing delays in digital hearing aids has shown that latencies as low as 20 to 30 ms are perceived as disturbing for people with mild-to-moderate hearing loss[10]. Even for individuals with normal hearing, speech production is affected when delays exceed 30 ms[11]. The coupling of a wireless headset to both Android and iPhone devices produced longer latencies that were well over the acceptable (< 20 ms) range. Most apps, however, include disclaimers that apps should be used with or prompt connection to wired earbuds to avoid signal delay, although connection to wireless headsets are possible (*e.g. Fennex, Petralex, Super Hearing Aid, Hearing Aid Master*). All apps improved SNR but, across Android apps, improvements were small (0.48 – 3.90 SNR) compared to iOS (0.84 – 18.11 SNR). Only apps on iOS had latencies that approximated acceptable signal delay and showed significant SNR improvement. The iOS apps used in the study of Amlani et al. (2013)[7], which showed speech recognition performance and amplification comparable with an audiologist fitted hearing aid, were no longer available.

None of the participants indicated a preference for the use of an app as opposed to a hearing aid. Following conversations while using the app was rated favorably by participants, yet aspects such as own-voice and background noise amplification were concerns. It should be kept in mind that the free-trial versions of apps, like *Petralex* used for subjective listening evaluation in this study, did not allow for settings like own voice suppression and noise reduction. The option to access more premium settings (e.g. own voice suppression) and better SNR improvement would depend on a person's willingness to pay for the application.

Hearing aid apps have the potential to increase global accessibility to amplification at reduced cost, increase awareness of hearing loss and reduce stigma related to wearing hearing aids in the future[7]. In addition, periodic app-updates could ensure that the user always has the latest software and features available. A problem with current apps, however, could be that self-administered, diagnostic hearing tests, incorporated with the app to determine amount of amplification, are usually some variant of international gold-standard pure tone audiometry. Remote pure tone testing of this from may have variable accuracy for different degrees of hearing loss, devices or earphones[12]. Although the better performing apps (*Fennex and Petralex*) use hearing aid algorithms to apply amplification, inaccurate hearing results could lead to inappropriate over- or under amplification. In addition, the performance of hearing aid apps is not uniform across devices, or platforms (iOS or Android). In conclusion, some hearing aid apps, such as *Fennex* running on iOS, could potentially benefit people with hearing loss but, at least for now, should be coupled with wired headsets for optimal performance. For Android smartphones, increased signal delays should be expected. Further developments to minimize latency and provide valid self-hearing test procedures, would be a helpful step towards improving the apps.

REFERENCES

1. Ferguson MA, Kitterick PT, Chong LY, Edmondson-Jones M, Barker F, Hoare DJ. Hearing aids for mild to moderate hearing loss in adults. Cochrane Database of Systematic Reviews. 2017(9).
2. Amlani AM. Application of the consumer decision-making model to hearing aid adoption in first-time users. Seminars in hearing 2016 May (Vol. 37, No. 02, pp. 103-119). Thieme Medical Publishers.
3. Simpson AN, Matthews LJ, Cassarly C, Dubno JR. Time from hearing aid candidacy to hearing aid adoption: A Longitudinal Cohort Study. Ear and hearing. 2019 May 1;40(3):468-76.
4. National Academies of Sciences, Engineering, and Medicine. Hearing health care for adults: Priorities for improving access and affordability. National Academies Press; 2016 Sep 6.
5. Barker AB, Leighton P, Ferguson MA. Coping together with hearing loss: A qualitative meta-synthesis of the psychosocial experiences of people with hearing loss and their communication partners. International Journal of Audiology. 2017 May 4;56(5):297-305.
6. Immediately in effect guidance document: Conditions for sale for air-conduction hearing aids guidance for industry and Food and Drug Administration Staff [Internet]: US Food and Drug Administration. 2016 Dec [Updated 2018 Oct 05; cited 12 Aug 2019]. Available from: http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM531995.pdf
7. Amlani AM, Taylor BR, Levy C, Robbins R. Utility of smartphone-based hearing aid applications as a substitute to traditional hearing aids. The Hearing Review. 2013;20(13):16-8.
8. Wilson BS, Tucci DL, Merson MH, O'Donoghue GM. Global hearing health care: new findings and perspectives. The Lancet. 2017 Dec 2;390(10111):2503-15.
9. The mobile economy: Global System of Mobile Communications. (2019). The Mobile Economy. 2019 [cited 5 Aug 2019]. Available from: https://www.gsmaintelligence.com/research/?file=b9a6e6202ee1d5f787cfebb95d3639c5&download
10. Stone MA, Moore BC. Tolerable hearing aid delays. I. Estimation of limits imposed by the auditory path alone using simulated hearing losses. Ear and Hearing. 1999 Jun 1;20(3):182-92.
11. Stone MA, Moore BC. Tolerable hearing aid delays. II. Estimation of limits imposed during speech production. Ear and Hearing. 2002 Aug 1;23(4):325-38.
12. Bright T, Pallawela D. Validated smartphone-based apps for ear and hearing assessments: a review. JMIR rehabilitation and assistive technologies. 2016;3(2):e13.