Check My Fit helps users put on their hearing aids

Qi Yang, PhD; Michalis Papakostas, PhD; Jack Scott III, PhD; Greg Olsen, MS HCI; Kirill Kondrashov, PhD

ABSTRACT

Putting on hearing aids is a regular and essential task for every hearing aid wearer. Correct insertion of hearing aids can be challenging for many. Check My Fit is a smartphone-based tool via the ReSound Smart 3D app designed to make it easy for users to quickly take a photo of their hearing aid placement, to help them wear their hearing aids correctly. To evaluate the usability and potential benefit of Check My Fit, we conducted lab and field studies. We found that Check My Fit is generally easy to learn and to use, and that hearing aid insertions aided by Check My Fit tend to have higher quality than insertions without the tool. Check My Fit has the potential to provide real-world benefit to new users learning to insert their hearing aids.

Most Hearing Care Professionals (HCPs) have experienced the following: you have noticed a hearing aid user in a public place with their hearing aids inserted incorrectly, and had to control the urge to reach over and pop them in. HCPs know that when hearing aids are not worn correctly, they are usually more visible and may be less comfortable. Audiological benefit can be reduced, as the amplified sound may not be delivered appropriately to the eardrum, and feedback may occur. And there is also increased risk of losing the hearing aids as they may easily fall off unnoticed. Therefore, putting on hearing aids is a critical daily task for hearing aid wearers and a key skill that HCPs teach. However, the HCP does not have many take-home options to help users with this important aspect of wearing hearing aids. Significant others can be instructed to assist in assuring that the hearing aid user is wearing their hearing aids correctly, and visual guidance in hearing aid user manuals is available. In addition, using a mirror to help in putting on hearing aids is commonly used but gives an incomplete view. Mirrors that provide a wider viewing angle are available but are clunky to use and impractical for users to take along on their day.

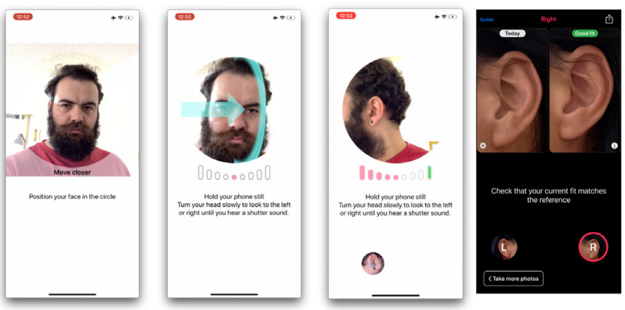
Even with a good view of the ear and hearing aid, the user must still rely on memory to know whether the insertion of their hearing aid is ideal for them. Remembering and then recognizing a visual scene is a more difficult than comparing two visual scenes. Further, recognition memory ability may decrease as people age.[1,2] This is relevant for learning hearing aid insertion since users are currently tasked with remembering what an ideal personal insertion looks like after they have left the fitting session.

ReSound follows the philosophy of Organic Hearing™ in developing hearing aid systems. The principles of Organic Hearing provide guidance to create solutions that help people to hear naturally, feel natural and connect naturally to their surroundings and other devices. The principle of feeling natural means that we offer solutions that minimize physical effort and enhance comfort for the user. Consistent with this principle, ReSound introduces Check My Fit to support users in putting on their hearing aids so that they can wear them comfortably, confidently and securely, as well as get the intended benefit throughout their day. Check My Fit is a smartphone-based, automated solution that lets users quickly take a photo of their hearing aid placement and compare it against a reference ideal insertion. This overcomes the issue of a) not being able to easily see their specific hearing aid on their own ear, and b) having to remember what a good insertion is supposed to look like. Furthermore, Check My Fit is initially a tool for Receiver-in-Ear (RIE) hearing aid styles, which accounts for 81% of hearing aids sold in the US.[3] This paper describes the technology behind Check My Fit, and presents evidence that it is easy and effective for hearing aid users to learn and use, and provides potential benefits for novice hearing aid users.

Human Interface Design

Taking a photo of oneself – a selfie – is a common use of smartphones that is easy for most people. The simplicity of selfies on smartphones inspired us to explore how this could be applied to checking hearing aid fit. While a selfie is easy, taking a photo of one's ear is difficult. A user holding a smartphone next to their ear will not be able to see the screen and properly frame the photo, nor can they easily press the shutter button. The design of Check My Fit in the ReSound Smart 3D™ app extends the selfie interaction by automating the process of framing and taking ear photos in the following steps (Figure 1):

- Using the smartphone's front-facing camera, Check My Fit guides a user to center their face on the screen (Figure 1a).
- A face-tracking algorithm is used to interactively guides the user to slowly turn their head to the left or right side while holding the smartphone steady in the original position (Figure 1b).
- As the user turns their head, we use computer vision to locate their ear. When an ear is detected and stable in a good position, a photo is taken and cropped automatically. The tool provides near-continuous auditory and tactile feedback throughout this process since the user cannot always see the screen (Figure 1c).
- After the photo is taken, a side-by-side user interface allows for quick comparison of the current photo against a reference photo, which was captured during the initial HA fitting session under HCP guidance (Figure 1d).



a. framing

b. guide to turn head

c. ear photo taken

d. comparison with reference

Figure 1. Check My Fit interaction design flow: (a) Guide to position face in frame (b, c) Interactive instructions to take ear photos (d) Comparison with reference photo.

Check My Fit provides redundant auditory, visual and tactile feedback on the smartphone to keep users informed and engaged in the photo-taking process. Specifically, when framing the user's face, assistive text and an animated frame are provided. Once the user's face is properly framed, an arrow prompts the user to turn their head. A dynamic progress visualization with audio tones and haptic feedback, all corresponding to the degrees of head turning in real-time, also aim to guide the user to intuitively operate Check My Fit. The continuous feedback helps to guide users through the head-turning gesture even when they can no longer see the screen. Lastly, anticipatory beeps and a shutter sound play when a stable ear is detected and the picture is taken. This auditory feedback informs the user to keep the phone steady and wait for the shot while they can no longer see the screen.

Software architecture

The Check My Fit prototype was built for iPhone on the iOS platform , although this feature is commercially available for both iOS and Android™. We used ARKit[4] to track the orientation of the user's face in real-time using the front-facing camera and sensors. ARKit face-tracking uses structured-light depth sensing hardware that is present on recent iOS devices. The face orientation is used to drive real-time audio, visual, and haptic feedback mentioned above. When the user's face is turned horizontally to more than 40 degrees, a custom-built ear- detection computer vision model is activated. Once an ear has been detected in the camera image stream and deemed stable, an image is captured automatically and cropped around the ear. Both face tracking and ear detection run in real-time.

Download on the App Store | GET IT ON Google Play

To introduce Check My Fit to new users, we created a short 30 second tutorial video showing brief usage of the tool. This video was used in the studies described in this paper.

EAR DETECTION

We trained a computer vision model based on the You Only Look Once (YOLO) version 2 real-time object-detection algorithm[5] to recognize ears. We gathered and manually annotated 1000 images from the public domain and from our preliminary user study. Guided by existing work on avoiding bias in machine learning models,[6] our training images covered various skin tones, ethnicities, and ages, as well as perspectives, lighting conditions, and ear sizes to account for user diversity and using the tool in different situations.

QUALITATIVE EVALUATION OF EAR DETECTION

The ear detection model was qualitatively evaluated by the authors, one of whom is a highly experienced audiologist. We ran the model offline on a test dataset of 255 images, then expanded the detected ear bounding box to a square based on its largest dimension to show more context to the user. This is identical to how Check My Fit uses the model. The cropped images based on the expanded bounding box were qualitatively rated. Each rater assigned a pass or fail score to each output image based on the quality of the crop. An image passed only if an ear was detected and centered in the cropped image and the crop boundaries were relatively tight around the ear (See images at Figure 2). The qualitative assessment showed that the detection succeeded in 97% of the test dataset and the raters showed high agreement on which images were considered a pass, suggesting that the ear detection model is robust.

User studies

We conducted two studies to evaluate the performance of Check My Fit: A small usability-focused lab study where participants used the tool in a one-hour session, then a 2-week field study simulating the on-boarding/adaptation period of typical new hearing aid wearers to further examine potential benefits of Check My Fit in supporting self-insertion.

In both studies, we rated insertion quality using a subjective scale from 0 to 10 aiming to match the visually observable hearing aid insertion depth, with 10 being an optimal fit and 0 corresponding to the receiver not inserted at all (see Figure 2).

Study 1: In-lab pilot study

We conducted an initial study to evaluate usability of Check My Fit, whether users can be trained to visually assess the quality of hearing aid insertion similar to an HCP, and to quantify the relationship between visual quality and acoustic quality of the hearing aid insertion. Check My Fit was compared with self-insertion not using any helping tools and with self-insertion using a foldable, handheld mirror. Participants were fit with ReSound RIE hearing aids coupled to closed domes and programmed with 15 dB flat insertion gain. Audioscan Verifit was used to measure real ear insertion gain (REIG).

Study design

Seven employees of ReSound who did not work in engineering or audiology participated. They were 41 – 66 years old, including 4 males and 3 females. All reported competency with general smartphone usage. Two participants reported prior hearing aid experience. Each participant was trained on proper insertion of the hearing aids and allowed to practice and visually assess insertion quality using a handheld mirror. A reference ear photo of the HCP's correct hearing aid placement was taken, and participants were then asked to learn to use Check My Fit without instruction. They inserted the hearing aids themselves several times in a single 90-minute session.

There were 5 user insertion conditions:

1. Insertion without any tool
2. Insertion using Check My Fit
3. Insertion using foldable mirror
4. Forced error assessed with Check My Fit
5. Forced error assessed with foldable mirror

To assess acoustic quality of different visual insertion qualities, the HCP then inserted the hearing aids at various insertion ratings as shown in Figure 2. REIG was carried out for each rating.

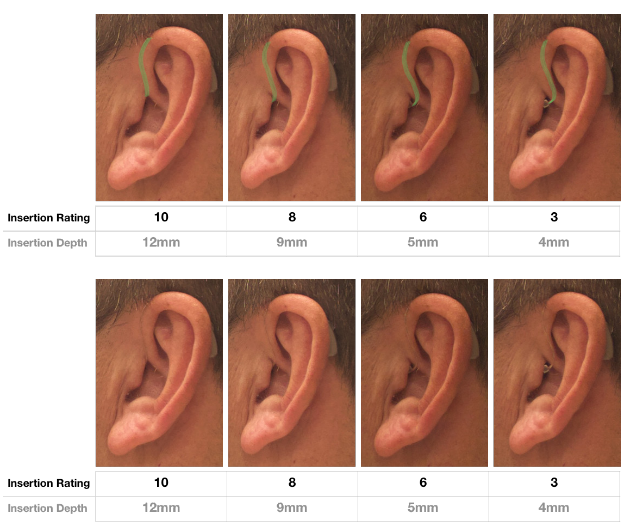


Figure 2. Example of insertion quality ratings, the score corresponds to insertion depth as measured from the external auditory meatus to the most lateral portion of the receiver. The receiver wire is highlighted in the top panel to better illustrate the insertions.

For forced error tasks, the HCP first inserted the hearing aid at an intentionally poor insertion quality of 3. Participants were instructed to assess the insertion quality using Check My Fit or the foldable mirror and were asked to adjust the insertion as needed. We wanted to observe how these two tools helped them assess and improve insertion quality from a common starting point.
After each insertion task, the HCP measured insertion depth and rated the insertion quality. The order of task pairs 2,3, and 4,5 were balanced to avoid priming effects. At the end of the session a demographic survey and a short interview was administered.

Results

USABILITY

Check My Fit was found to be easy to learn and use, enabling participants to take a photo of their ear quickly. With just the tutorial video, all participants were able to learn to use Check My Fit with most of them learning the correct usage immediately. This suggests that the video tutorial alone was effective in this regard.

At the conclusion of the study, 5 out of the 7 participants preferred to use Check My Fit and two preferred the foldable mirror as a tool to aid hearing aid insertion. Participants who preferred Check My Fit liked being able to compare their insertion photo against the reference photo, which underscores the cognitive advantage of visual comparison without relying on one's memory. Additionally, they liked that the app could be available on their phone and would not require carrying an additional tool. One participant who preferred the mirror expressed that a mirror provides real-time viewing of the ear during insertions, while taking a photo is not real-time.

INSERTION DEPTH AND QUALITY

Participants were able to achieve high-quality self-insertion regardless of whether they used Check My Fit or the mirror. Since the participants' initial skills were already high, we did not see any improvement from the use of the two tools. Furthermore, in the forced-error trials, all participants were able to correct a poor quality insertion to a high quality one (average score of 8-9) using both Check My Fit and the mirror. The high degree of competency is likely due to the fact that participants performed insertions immediately after instruction as well as the familiarity some already had with hearing aids.

INSERTION GAIN

We found that a small change in insertion depth of the hearing aid speaker can have a marked impact on the gain delivered to the ear. There was a measurable reduction in REIG when the hearing aid receiver was placed at a shallower location in the ear canal than originally set and prescribed by the hearing care professional.

Almost all participants had a maximum deviation greater than 6 dB and an average deviation greater than 2.5 dB across all frequencies when insertion quality (depth) was at a rating of 3. Even at a higher insertion quality of 8, the maximum deviation is still greater than 5 dB for nearly all participants (Figure 3), thereby exceeding the recommended 5 dB margin of error in the hearing aid fitting process.[7]

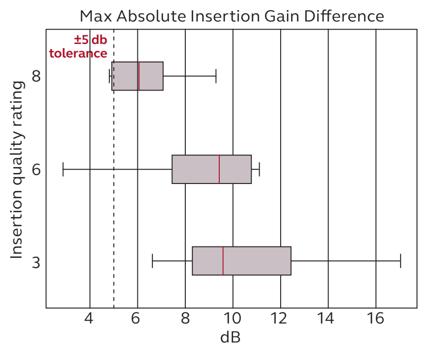


Figure 3. Maximum absolute deviation of insertion gains for different insertion qualities (score of 8, 6, 3 compared to an "ideal" score of 10). In most cases the deviation is greater than 5 dB.

POTENTIAL FOR ACOUSTIC FEEDBACK

Unsurprisingly, we found that poorer quality and shallower insertions result in higher chance of feedback from the hearing aid. We used Maximum Stable Gain (MSG) as a measure; a lower MSG implies higher likelihood of feedback. When insertion quality is decreased to a rating of 3, we saw a median minimum reduction in MSG of 11.6 dB.

Study 2: New wearer field study

A field study was also carried out to evaluate potential benefit of Check My Fit in a real-life, unsupervised environment. Further, the field study included a more diverse population to ensure that the ear detector works on people with a range of skin tones.

Seventeen people who did not have hearing aid experience participated. Hearing status was not evaluated since the purpose of the study was to evaluate the daily use of Check My Fit and dummy hearing aids were used. Average participant age was 62 years old (range 48-79 years), split between 9 female, 8 male. All participants were regular smartphone users, with more than 90% using iPhone. We attempted to include a variety of skin-tone and ethnic backgrounds to ensure the trained ear detection model is robust. Specifically, we recruited 7 participants of darker/brown skin tone (Type V and VI in Fitzpatrick scale), 3 of medium (Type II, III) skin tone and 7 of light skin tone (Type I).[8] Although not a recruitment criterion, all participants were right-handed.

Participants were provided with an iPhone that had Check My Fit installed, and dummy RIE hearing aids. Each participant attended three sessions and completed a daily hearing aid insertion task throughout a two-week period (see Figure 4). For the purpose of the study, cloud-synching functionality was implemented in the app such that photos could be reviewed by the study facilitator remotely.

We asked participants to use Check My Fit for insertion only on their non-dominant hand side with the expectation that it naturally may be more difficult to place the hearing aid. As a control, they did not use Check My Fit to place the hearing aids on their dominant hand side.

Procedure

DAILY TASK

Participants completed a 2-part task daily for two weeks, except for three days when they were asked to take a break (as shown in grey circles in Figure 4). The first task was insertion; participants were asked to put on the hearing aids and use Check My Fit on their non-dominant side ear to verify the insertion quality, reinserting if they judged necessary. Participants were advised to use other tools such as a mirror to verify the insertion on the dominant side if they wished. Once the participant was satisfied that they had inserted the hearing aids correctly, they proceeded to the second task.

Data was collected in the second part of the task, where participants took photos of both ears using Check My Fit. The photos in this stage were only shown by the app as small thumbnails to prevent the participant from using them to evaluate insertion quality. After the task, the participants removed the dummy hearing aids and did not wear them for the rest of the day.

Day 0 - First session: The initial session included obtaining informed consent, instruction on HA insertion and the daily task.

Week 1: Participants were asked to complete the Daily Task each day (Figure 4, blue circles).

Day 7 - Check-in call: A video call was performed with the participant to check in. Participants were asked to take ear photos using Check My Fit, then they were asked to insert their dummy hearing aids and take another set of photos. The insertion photos were reviewed to rate their insertion quality. If the insertion quality was judged to be poor by the HCP, participants were encouraged to re-insert the devices. Participants were encouraged to provide feedback on the daily task and express any concerns or comfort issues they were experiencing. They were then briefed on the tasks for Week 2.

Week 2: Each participant completed the Daily Insertion Task for 2 days following the Check-in Call. They then took a 3-day break, and then performed the Daily Insertion Task again for the final 2 days of the study.

Day 14 - End of study session: During the last session, participants were asked to take ear photos with Check My Fit, and then insert their hearing aids and take another set of ear photos. Participants were then asked to rate their confidence on their hearing aid insertion before seeing the ear photos. They were then asked to rate the quality of their insertion based on visual comparison with the reference photo, and were asked if they would reinsert their hearing aids based on their evaluation.
The participants completed another short online survey within 24 hours, concluding their 2-week participation.

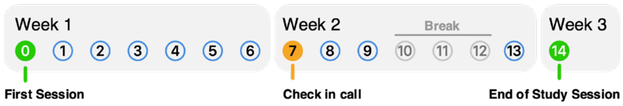


Figure 4. Field study schedule.

Results

Overall, we collected a total of 1428 ear photos over 234 individual sessions, covering about 17 hours of interaction time.

INSERTION QUALITY RATING

A research audiologist along with two audiology graduate students visually inspected each of the 1428 photos taken by participants and rated them from 0-unacceptable insertion (e.g., receiver not inserted into the ear) to 10-optimal insertion (Figure 2). To evaluate consistency between the raters, we conducted a repeated-measures ANOVA with rater and method (Check My Fit and Control) as within-subject factors. The ANOVA showed a significant main effect of rater [F (2, 32) = 5.7 P = 0.008, η_{p2} = 0.262] and method [F (1, 16) = 5.0, P = 0.039, η_{p2} = 0.239] but no interaction between rater and method [F (2, 32) = 1.7, C = 0.206, η_{p2} = 0.094]. This indicates that the insertions are consistent. The significant effect of method is indicative of overall higher ratings for Check My Fit, on average.

INSERTION PERFORMANCE

We selected the final pairs of ear photos from each task session of each participant to evaluate the quality of the insertions from using Check My Fit versus the Control side, totaling 471 photos. We selected only the final photos since participants typically take multiple photos during the insertion process, likely while they adjust their insertions. Thus, the last photos are after they had completed insertion and considered it to be good. We conducted a repeated-measures ANOVA on the mean rating of each participant per method before and after the three-day break and found a significant main effect of method [F (1, 15) = 6.2, P = 0.025, η_{p2} = 0.293]. Time (insertion performance before or after the break) was not a significant factor [F (1, 15) = 0.009, P = 0.927, η_{p2} = 0.001], and we found no interaction between time and method [F(1, 15) = 0.7, P = 0.410, η_{p2} = 0.046]. This suggests that participants perform better insertions with Check My Fit than without. Overall, Check My Fit insertion quality was rated 0.3 to 0.5 units higher than the Control and the break in the second week did not affect the insertion performance.

Plotting the average rating of Check My Fit versus Control for each participant (Figure 5), we see that 70% of participants had insertions rated as better for Check My Fit than Control. Some of these were better by a large margin, while for the 5 participants where Control was better than Check My Fit, the margin was smaller.

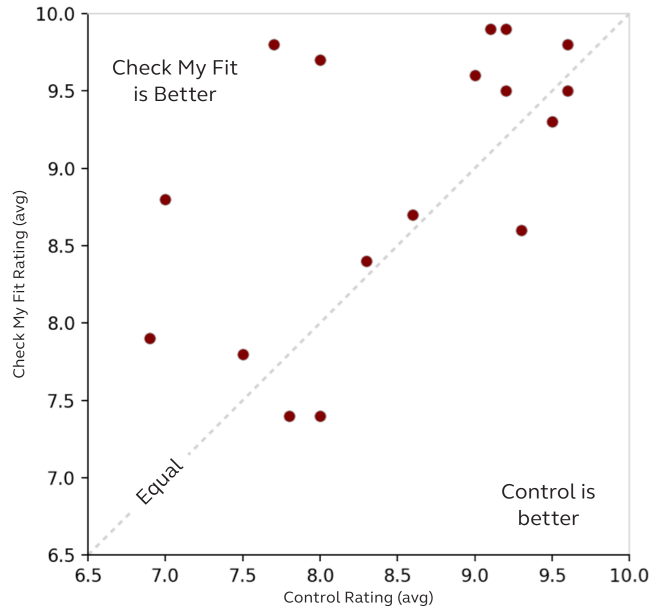


Figure 5. Individual participant's average Check My Fit rating against Control rating shows that many more perform better with Check My Fit than without (Control). Data points above the diagonal line indicate better rating with Check My Fit, and points below the diagonal line indicate better rating with Control.

There was also a significant correlation between insertion methods (r = 0.580, P = 0.015) which could mean that participants were generally good at both methods, or not very good at either. Several participants were skilled at both methods, as shown by the cluster of datapoints in the upper right corner of Figure 5.

DISCUSSION

Study 1 showed that Check My Fit is highly learnable and usable, and verified that visually observable insertion quality (insertion depth) is strongly related to the amplification delivered to the ear as well as the risk of acoustic feedback. A small deviation (e.g. quality rating of 8) from the ideal insertion introduced significant deterioration in accurate gains and MSG, underscoring the audiological importance of hearing aid users being able to put on their hearing aids correctly.

In Study 2, we found that insertions assisted by Check My Fit to have higher quality than the control condition. The effect was significant, persisted throughout the 2 weeks of the study, and was retained after a short break. If Check My Fit had no effect on insertion quality, we would expect the Check My Fit side to be lower in quality due to it being the non-dominant side. However, we observed the Check My Fit side to have slightly higher quality. This may suggest that the quality advantage of Check My Fit is bigger than what we measured.

Notably, while a small number of participants did express uncertainty on how to assess their insertion quality, or the goal of the insertion task, (e.g., "I'm not sure what to look for"), the same participants still showed insertion improvement with Check My Fit versus Control.

This suggests that just having a visual reference can be beneficial for users to intuitively evaluate their insertion over relying on memory, even if they did not express how they make such evaluations. In general, we saw most participants performed self-insertions well, achieving a rating above 7 each day. Interestingly, we did not observe significant improvement of insertion quality over time.

Both studies indicated that Check My Fit is easy to learn and highly usable. Almost all participants were able to learn and use it after watching a short video with no instructions. They retained the skill while using Check My Fit independently at home. Participants were able to take a usable ear photo successfully and quickly (often within seconds), and with very few retries (with an approximately 9% failure rate where a photo had to be retaken).

SUMMARY

Check My Fit addresses a widely recognized issue with learning to use hearing aids and is inspired by the ReSound Organic Hearing principle of feeling natural. Check My Fit is a smartphone-based automated solution via the ReSound Smart 3D app enabling users to quickly take a photo of their hearing aid placement and compare it against a reference ideal insertion. We designed it to assist wearers to insert their hearing aids, an important daily task which can be challenging. Its design was inspired by and extended the typical interaction of taking a selfie. We conducted a lab study and a two-week field study to evaluated usability and user benefit of Check My Fit. Overall, we found that Check My Fit is easy to learn and use, robust in independent usage by new hearing aid users, and its usage is correlated with better insertion quality.

References

1. Glisky EL. Changes in cognitive function in human aging. Brain aging: Models, methods, and mechanisms. 2007 Apr 19;1.
2. Rhodes S, Greene NR, Naveh-Benjamin M. Age-related differences in recall and recognition: A meta-analysis. Psychonomic Bulletin & Review. 2019 Oct;26(5):1529-47.
3. Strom K. Hearing Aid Sales Increase by 37% in 2021. Hearing Review. https://hearingreview.com/practice-building/marketing/surveys-statistics/hearing-aid-sales-increase-by-37-in-2021-and-by-12-over-2019. Accessed 2022/05/09.
4. https://developer.apple.com/documentation/arkit/content_anchors/tracking_and_visualizing_faces. Accessed 2022/05/09.
5. Redmon J, Farhadi A. YOLO9000: better, faster, stronger. InProceedings of the IEEE conference on computer vision and pattern recognition 2017 (pp. 7263-7271).
6. Buolamwini J, Gebru T. Gender shades: Intersectional accuracy disparities in commercial gender classification. In Conference on fairness, accountability and transparency 2018 Jan 21 (pp. 77-91). PMLR.
7. Gatehouse S, Stephens SD, Davis AC, Bamford JM. Good practice guidance for adult hearing aid fittings and services. British Association of Audiological Scientists Newsletter. 2001;36.
8. Roberts WE. Skin type classification systems old and new. Dermatologic clinics. 2009 Oct 1;27(4):529-33.

ReSound GN

Manufacturer according to FDA:

GN ReSound North America

8001 E. Bloomington Freeway
Bloomington, MN 55420
USA
1-800-248-4327
pro.resound.com

ReSound Government Services

8001 E. Bloomington Freeway
Bloomington, MN 55420
USA
1-800-392-9932
gs.resound.com

Manufacturer according to Health Canada:

ReSound Canada

2 East Beaver Creek Road, Building 3
Richmond Hill, ON L4B 2N3
Canada
1-888-737-6863
pro.resound.com

MK605593

MK605593 Rev A 2022.06