Assessing the Utility of Mobile Applications with Support for or as Replacement of Hearing Aids

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Abstract

Hearing aids are becoming more and more important in an aging society. One of the main aspects is speech intelligibility. This requires algorithms that separate speech signals from other sources of sound and filter the latter ones away from the source. Such algorithms have a high computational cost and are usually not employed on hearing aids themselves. Most importantly, algorithms implemented on embedded systems like on hearing aids are not universally portable to any other device, whereas such flexibility exists to a much higher degree on smartphone operating systems. The growing prevalence and high processing power of smartphones (including their operating systems) on the market gives rise to the idea of running the algorithms on a smartphone app instead (after recording the input signal with multiple microphones attached to the phone), and having the results sent to a hearing aid for playback. A state-of-the-art assessment of mobile applications that provide related functionality is necessary to determine the necessary fields of improvement and to determine technical, already feasible solutions and applied features in the market. This requires a detailed development of criteria that effectively and formally measure the utility of such applications. This paper develops such criteria and demonstrates a way to apply them in practice.

1. Introduction

An aging society has the opportunity to use the rising potential of medical-technical developments for improving every-day situations in the form of improved social integration. Aging usually goes along with a loss of hearing. People with unimpaired hearing, in addition to being able to perceive more sounds altogether, are also able to filter sounds according to signals important to them and to remove unimportant signal components. These two latter abilities are lost by people with a hearing loss. They are also not relearned through the classical use of a hearing aid, since both directional information of selective hearing and the filtering of voices after enhancement by the hearing aid are lost. This artificial enhancement is therefore perceived as a wall of noise that cannot be separated - as with an intact ear -
by concentrating on a voice or sound. As a result, audible ambient noise is perceived as disturbing, which leads to a lack of acceptance of hearing aids and quite undesirable frustration after the loss of major natural hearing capabilities.

As for the state-of-the-art of digital hearing aid technology, complex acoustic everyday life situations that include multiple speech signal sources, ambient noises and resonance are a big challenge. Digital hearing aids already possess signal processing functions that enhance speech signals and reduce disturbing ambient noises, but that vary strongly in performance with different every-day situations. Efficient algorithms are needed that guarantee speech intelligibility both in simple and in highly complex acoustic everyday life situations.

A multitude of speech signal processing techniques has been developed, but only a small number is actually used commercially in hearing aids. Reasons for this are high required computational performance, process delays, musical artifacts, or, good performance could only be verified in the laboratory. Within the context of this paper’s related work, the SMARTNAVI project, it is an important goal to analyze everyday situations by constellations in which social integration and autonomous actionability in social environments is restored and secured through an intuitive human machine interface in the form of a touch display. The goal is the self-adaptive identification (i.e. separation) of conversational partners and other sound sources like open windows or doors, further people in the near environment and the concentration on (i.e. enhancement of) specific voices through manual selection. This is also possible in environments like public transport, social meeting like the proverbial coffee party, the retirement home, the nursing home and family celebrations, just to name a few.

The technical realization is aimed at on a smartphone platform in a preliminary design study. For this purpose, an assessment of related state-of-the-art smartphone apps that already provide at least some of the required functionality is necessary. This requires a well-defined set of multiple criteria by which to determine the actual utility of each app, and a concrete procedure by which to apply those criteria to obtain objective evaluations. Only after such an evaluation, the most urgent fields of improvement is identified and prioritized by criterion. The purpose of this paper is therefore to establish a meaningful methodology for assessing the utility of state-of-the-art mobile applications for supporting hearing aids.

Afterwards, a compilation of the relevant apps is presented, that are then evaluated by the aforementioned methodology to demonstrate the practical applicability of this methodology, also for future references.

2. Developing the methodology

The Cost-Utility Analysis (CUA) is used as a general framework for evaluating each smartphone app. This method is simple from its onset, flexible in its application, and practically applicable as a general weighted scoring where multiple factors need to be weighted, all of which is required for the task at hand.

Let both the costs and the weights be measured on a floating point scale from 0.0 to 1.0. In the case of this work, the comparison groups are the criteria by which apps are evaluated, costs (positive in this context) are the values that an app scores for each criterion, and utilities are the weightings applied to the costs. The cost-utility-function applied to a single app is simply the sum of products between scores and weights. The result is the overall weighted score that the app has and that indicates the degree of its utility.

A catalogue of comparison criteria with their weightings is first developed in the following. The criteria and ideas about how to apply them to a given app for obtaining scores are derived by argumentation according to SMARTNAVI. They are also inspired by what is discovered by roughly examining relevant apps to guarantee their practical relevance. The same holds for the weightings. The following criteria are not sorted by priority, but a prioritized presentation of the applied weightings is given at the end of this section.

Universal platform support and popularity: It is examined how cross-platform the app is with regard to the operating system on the mobile device and how popular it is for users on the respective platform. Cross-platform apps potentially attract a bigger target group than those that are written, e.g., for the Android only, or Apple iOS only. The 2013 market shares in worldwide smartphone sales to end users by operating system (currently 78.4% (i.e. 0.784) for Android, 15.6% (i.e. 0.156) for iOS) influences the metric for this criterion. It is combined with the app’s per-platform rating: The market share of an operating system supported by the app is multiplied by the app’s normalized customer rating for the respective platform (normalized meaning as a percentage of the maximum 5-star score, i.e. on a scale from 0.0 to 1.0). Finally, all such products are simply added together. This way, the more important the support
of a particular operating system is, the better it is considered in this metric while taking active users into account. Furthermore, the more operating systems are supported while being popular, the higher the metric value.

**Creation of hearing tests:** An important question with regard to the functionality of the app is, if it offers a hearing test in which the user can give feedbacks for certain test sequences. In the ideal case, both a frequency range test (Which frequencies can the user hear at all?) and a frequency distinguishing test (Which frequency differences can the user notice?) is offered.\(^8\)\(^9\) These results also flow into the signal processing algorithm, since it allows to distinguish, which frequencies need to be enhanced at all and to what degree\(^1\). Most apps do not offer such a test but only allow the user to control filtering options on the basis of his own foreknowledge. Such apps are evaluated with 0.0 by this criterion, the other ones with 1.0.

**Creation of profiles:** This criterion of profiles for different environments is subdivided into three sub-criteria:

In an ideal case, the user is able to create and use profiles for different acoustic environments in which frequencies of the acoustic signals are filtered to a different degree. Also, in the ideal case, it is possible to automatically activate such a profile after automatic detection of the sound environment. After such an environment becomes known through the activation of a profile, the kind of signal processing necessary per frequency range has to be employed.\(^9\)\(^10\) Apps using such profiles get a score of 0.5 for that (if no profiles are used at all, but the user at least has some control of the signal processing, e.g. bass and tremble adjustments, for the current situation only, the app at least gets a score of 0.25 for this part). If they also support their creation by the user himself, the score is raised by 0.25, and if the app can automatically detect and activate the right profile for the current environment, the score is raised by another 0.25. Only if none of all this is supported, the overall score is 0.0. The full score of 1.0 is reached only if all aforementioned abilities are part of the app.

**Support for individual settings per ear:** Since hearing ability in some cases differs in human beings from ear to ear\(^1\), it is of course desirable that the app is able to adapt the signal processing to the abilities of each ear individually, i.e. that two separate processes conduct signal processing separately and output it separately. Depending on how strongly an app supports this, i.e. from not at all to only the output volume or full signal processing per ear\(^11\)\(^12\), the scoring ranges from 0.0 to 1.0.

**Input support:** This criterion refers to which kinds of input data are supported for which kind of interfaces of the periphery and is subdivided into sub-criteria:

One is the **microphone type**, which refers to the adequacy of the microphones for the given purpose: Since they are tailored to making phone calls, internal devices have the particular disadvantage of being optimized for speech signals from the owner who directly speaks into them. Other sound sources (gusts of wind, rubbing of pieces of cloth etc.) are recorded like noise signals. More sophisticated types of microphones that eliminate these problems are possible if tailored to making phone calls, internal devices have the particular disadvantage of being optimized for speech signals from the owner who directly speaks into them. Other sound sources (gusts of wind, rubbing of pieces of cloth etc.) are recorded like noise signals. More sophisticated types of microphones that eliminate these problems are possible if they are external.\(^13\) This aspect of input support is just as important as the second sub-criterion:

The second is the **simultaneous use of multiple microphones** (microphone arrays): Psycho-acoustic studies prove that binaural noise reduction strategies and signal source localization are indispensable for achieving speech intelligibility. Binaurally directed hearing aids use noise reduction methods based on multiple microphones. They utilize the inputs of the left and the right hearing aid\(^2\)\(^4\)\(^3\)\(^4\) If signal processing is to be performed on a smartphone instead of on the hearing aid, the following is therefore highly relevant: It matters, if (in addition to the microphones usually integrated into the device) also additional (usually external microphones) are utilized by the app simultaneously. The limitation to only the built-in microphone, or in general, to only one microphone used simultaneously, limits the ability of algorithms to separate signal sources for noise reduction in the app’s algorithm\(^1\).

In the usual case of only the built-in stereo microphone support, a grade contribution of 0.25 is given for the microphone type, otherwise a contribution of 0.5 (even if built-in types are not supported). Simultaneity contributes by 0.5, if present, otherwise it defaults to a contribution of 0.0.

**Output support:** Like the user profiles criterion, this criterion of output support is also subdivided into three sub-criteria, which are explained in the following. In analogy to the input support criterion, it refers to which kinds of output data are supported for which kind of interfaces of the periphery:

The goal of the project is the output of signals for hearing aids that really enhance a separated and filtered (i.e. processed) signal for a hearing impaired user\(^1\). Therefore, apps are preferred that also support output to hearing aids. In other words, the **output device type** matters. This sub-criterion is indifferent to the signal type output to the periphery (see next paragraph), which reduces its scoring contribution.
On the other hand, it is equally decisive which kinds of signals are send to the output periphery, i.e. if speech signals or only control signals for hearing aids are supported, or, in other words, the signal type:

Speech signals usually serve the purpose of direct display through the periphery device. In this case, the app itself takes over the complete signal processing after recording the analogue signal through the microphone and sends the result to the output periphery for display. The output periphery device has to be able to cope with the coding of the signals and be able to directly convert it for playback. Therefore, hearing aids only serve as a form of high quality headphone.

Control signals for hearing aids, on the other hand, only serve as a configuration of a hearing program fixed into the hearing aid. Moreover, the hearing aid continues to play the part of signal processing in algorithms, i.e. it continues to record sounds in its own environment, processes them with the help of the hearing program and displays the results. It is then only the parameters of the hearing programs (e.g. optimization to certain physical environments) that are steered from outside via the app in the form of transmitted parameters. Therefore, the app only plays the part of environment analysis.

Basically the following holds: The more signal processing is already accomplished on the smartphone itself to transmit properly processed speech signals to the periphery device, the more independence is achieved of the app’s compatibility with specific types of hearing aids. This means that, in the ideal case, hearing aids all receive and play back the same signal (i.e. speech), without the need to provide every device with control signals differently. The transmission of speech signals by the app is therefore to be preferred against pure control signals.

Another point is the kind of transmission channel, i.e. if the signals are transmitted by some kind of wire or wirelessly (e.g. Bluetooth). Wireless transmission is to be preferred for convenience sake.

Altogether, the combination of output device type (20% importance) together with the output signal type (speech or control signal, 75% importance) and transmission channel (5% importance) makes up this whole criterion of output support. Therefore, an optimal device type (hearing aids) contributes 0.20 to the scoring. If only headphones are used, the contribution is only 0.10. An optimal output signal type (sound signals) contributes 0.75 to the score (if only control signals are output, the device type contribution is only 0.15). As for the transmission channel, only in the case of wireless output transmission, 0.05 is added to the overall score (if only wired transmission is possible, the contribution is reduced to 0.02). All these sub-scores are added together to form the score for the criterion of output support.

Criteria not used: Criteria not used for this evaluation involve software costs, since only the functionality is important here to achieve social reintegration. The purpose of this research is scientific, not economic.

They also involve runtime performance: There are studies in the medical literature on tolerable delays for hearing aids. However, the application is not aimed at solving a time-delay problem to perform signal processing in realtime. Although desirable, there is no reason for it to result in a negative evaluation if it does not run in realtime. Social reintegration by coping with different life-critical and socially critical situations is the main focus. Therefore, even if just listening to processed recordings, the user still benefits and reconnect to the social environment.

Finally, most descriptions on smartphone apps by the vendor do not give a detailed insight into the algorithms used for signal processing, but only a general overview of the functionality. This makes it very difficult to evaluate existing algorithms against each other. Evaluation by the prestige of the vendor (company, organization or qualification) alone does also not serve as a legitimate method. It is therefore impossible to use the quality of the processing algorithm as a criterion for evaluation. However, the signal type criterion described under output support, partly being an indicator of what the algorithm of the app provides, serves as a lower substitute.

Weighting of the criteria: The following overview of criteria weighting is in the order of priority.

The highest priority is given to the output support (since the aforementioned criterion of algorithm quality is not possible as mentioned earlier): Ultimately, an app - in the best case - outputs signals to a hearing aid for optimized sound enhancement for the person affected by hearing loss. At the same time, the crucial part of the signal processing (separation and filtering) is preferably done on the phone, to achieve maximum flexibility and independence from the output device type (hearing aid). Therefore, the output format produced by the algorithm is a filtered speech signal instead of a control signal for the hearing aid. The criterion of output support therefore also indicates an aspect of the algorithm itself, namely its output product (speech or control signal) and target device (besides the transmission channel also included in this criterion, see the description under output support). Such requirements have a very high weight that makes up almost half of its usefulness for SMARTNAVI, therefore the weighting is set to 0.35.
Almost as important - as an indicator of what input size the running algorithm takes - is the input support: The larger the number of microphones accepted by the app’s algorithm, the better its potential of performing some kind of signal separation in its filtering. This criterion therefore gets a weight of 30%, or 0.3.

Without the ability to create profiles that are activated in a changed acoustic environment, the app does not serve as a useful tool for convenient and efficient social reintegration. The necessity of manual readjustment at every new situation by the user is not a practical solution, although it has to be said that the app, in this case, still “works”. The weight is therefore set to 15%, or 0.15.

Although - if not supported by the app - it is only a matter of duplication, i.e. running the algorithm twice as parallel processes and channeling each of the results to a different ear in some way, some weight (10%, or 0.1) is also given to the fact of whether binaural support comes out-of-the-box or not. Hearing loss occurs only on one as well as on both ears or to a different degree on both ears.18

Multi-platform support is preferable, but not essential, since - although the market of mobile operating systems is highly fragmented - the biggest share is held by Google’s Android, followed by Apple’s iOS, with a combined share of more than 90%7, i.e. almost the whole market. Hence most - and all of the apps evaluated here - are written for these two major platforms. Furthermore, user satisfaction only evaluates the status-quo: Users do not necessarily consider the high-level functionality demanded by SMARTNAVI. The weight applied to this criterion is therefore set to only 5%, or 0.05.

The ability to run hearing tests has the least priority, since this is something usually done professionally by an audiologist, employing an audiometer19 and many other additional tests20. It only serves as a convenient setup option in the personal adjustment procedure of the app’s algorithm. Minimal importance, i.e. a low weight of only 5% (0.05) is therefore applied to this criterion.

With the methodology now explained, its application to smartphone applications relating to SMARTNAVI functionality is conducted in the following sections.

3. Description of selected smartphone apps

A total of 10 different apps that cover the two main operating systems, iOS and Android, are chosen for evaluation on the basis of a web research: ReSound Smart and ReSound Control by GN ReSound21,25, miniTek RemoteApp by Siemens16,22, Test Your Hearing by Epsison-Zero8, Hearing Aid with Replay by Lemberg Solutions23, uHear by Unitron Hearing Limited24, uSound by Newbrick S. A.25 AUD-1 by Dr. Nick Clark13, soundAMP R by Ginger Labs Inc.11 and hearing help by Peer Dahl (from the Ingenierbüro für Nachrichten- und Datentechnik12,26). The following provides some descriptions of some of the apps and a tabular overview of the platforms supported including customer ratings (see corresponding additional references in the table). The full documentation of functionalities is obtainable from the respective sources and form the basis for the scoring applied to them in the next section.

ReSound Smart: This app is designed for the appendant ReSound LiNX hearing aid, which is the first hearing aid made for iPhone. No information is given as to whether it provides some kind of hearing test to influence acoustic signal processing. Profiles are employed by selection. But there is no clear indication as to whether they can really be created by the user. The referral to profiles as hearing programs in the references indicates that they pertain to the hearing program in the hearing aid, which are only created and set up by the hearing care professional and selected by the app. On the other hand, such a profile, or hearing program, used at a particular location are geo-tagged so that it is automatically be selected and employed the next time the user resides at that location. There is no hint at how different settings per ear are made. Also, nothing indicates a possibility to have additionally connected external microphones used as processing sources. The app is highly multi-functional: It supports the transmission of any sound - telephone conversations, music and other sound content to the Resound LiNX hearing aid. It is even possible to hand over the phone to a nearby conversational partner, to talk into it like into a microphone and have his speech automatically transmitted to his hearing impaired peer. In other words, the app supports sound signal input sources beyond the microphone (which is interesting as far as telephone conversations or recorded audio files are concerned) and direct output to the hearing aid. Signal transmission is fully wireless. However, it has to be said that all audio signal processing regarding filtering and enhancement is still done on the hearing aid. So only unprocessed signals are actually transmitted to the hearing aid. This comes in addition to control signals: The app only controls the settings
that the hearing aid receives from the phone and uses them to do the signal processing of likewise received acoustic audio signals, either from the phone or from its environment.  

**miniTek RemoteApp:** This app is designed to work together only with hearing aids by Siemens and also requires the so-called miniTek device, which is wirelessly connected to the phone by Bluetooth, and to which many different kinds of other devices are likewise connectable via Bluetooth (this also holds for external Bluetooth microphones, if available). All devices connected to the miniTek, including direct audio inputs connected to the phone (like external microphones) are - mutually exclusively - instructed to stream to the hearing aid, which alone performs the main signal processing. Similar to the two previous apps described in this paper, the miniTek Remote app controls and transmits the hearing program to be used to the hearing aid after manual selection. The hearing aids communicate with the miniTek device via the e2e wireless 2.0 standard. Apparently, this app offers no hearing tests and no per-ear settings. There also is a similar concept of no user-controlled profile generation within the app that is employed here, as in the two previous apps. Note that miniTek remote is not specifically designed for using the phone’s build-in microphone for streaming to the hearing aid, but only the audio input (e.g. a more sophisticated microphone).

**Test Your Hearing and uHear:** Test Your Hearing and uHear, like many other similar apps available, are simply designed to simulate only some of the tasks of a hearing care professional or audiologist, who would usually perform these tests on a much broader scale and better quality. There are usually no other functions for apps like these, or in other words, signal processing of speech signals is not the purpose of such apps.

**Hearing Aid with Replay:** This app is the first of the ten that is not geared towards any particular hearing aid, but simply a sound amplifier or equalizer and recorder (playback of processed sounds is only possible after recording). No hearing tests are offered by this app. Contrary to the previous apps, profiles are also an option to create by the user on the basis of an equalizer with different frequencies. The user controls the sound intensity he desires and reduce excessive loudness to concentrate on only the frequencies that are currently relevant. They are not detected automatically. As for per-ear settings, only the balance of the processed output signal is controlled by the app. The app uses the built-in microphone as its only input source and outputs the processed results to either earphones or Bluetooth A2DP headsets (not to device headsets).

**Remaining apps:** See the documentations in the corresponding references.

<table>
<thead>
<tr>
<th>App</th>
<th>Platforms (and normalized customer ratings relative to the maximum 5-star rating)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ReSound Smart</td>
<td>iOS 9 (2.5/5, i.e. 0.5)</td>
</tr>
<tr>
<td>ReSound Control</td>
<td>Android 28 (3.8/5, i.e. 0.76) and iOS 29 (3/5, i.e. 0.6)</td>
</tr>
<tr>
<td>miniTek RemoteApp</td>
<td>Android 10 (3.8/5, i.e. 0.76)</td>
</tr>
<tr>
<td>Test Your Hearing</td>
<td>Android 8 (4.3/5, i.e. 0.86)</td>
</tr>
<tr>
<td>Hearing Aid with Replay</td>
<td>Android 27 (4.3/5, i.e. 0.86)</td>
</tr>
<tr>
<td>AUD-1</td>
<td>iOS 30 (n/a, but 4/5 for closely related BioAid app, i.e. 0.8)</td>
</tr>
<tr>
<td>uHear</td>
<td>iOS 31 (3.5/5, i.e. 0.7)</td>
</tr>
<tr>
<td>uSound</td>
<td>Android 32 (4.3/5, i.e. 0.86)</td>
</tr>
<tr>
<td>soundAMP R</td>
<td>iOS 33 (3.5/5, i.e. 0.7)</td>
</tr>
<tr>
<td>Hearing Help</td>
<td>iOS 34 (not available, but rated 4.5/5 by Apple, i.e. 0.9)</td>
</tr>
</tbody>
</table>

### 4. Scoring results and evaluation

After applying the evaluation criteria described in section 2 to the apps described in 3 and multiplying them by their corresponding weights, the following scoring is obtained for them:

The results show that those apps solely dedicated to providing hearing tests (Test Your Hearing and uHear) obtain the lowest overall weighted score below 10%, as it is to be expected due to a lack of scoring points in almost every other criterion. In other words, those apps are the least useful.

Those apps that do more than just testing, but are tailored to a particular hearing aid model (ReSound Smart/Control and miniTek Remote App), also still maintain a relatively low score below 50%. This is largely due to their low scoring in output support (which is severely reduced by the lack of processed speech signal output). Such low output support...
Table 2. Scoring results.

<table>
<thead>
<tr>
<th>App</th>
<th>Output</th>
<th>Input</th>
<th>Profiles</th>
<th>Settings per ear</th>
<th>Platforms/popularity</th>
<th>Hearing tests</th>
<th>Weighted score</th>
</tr>
</thead>
<tbody>
<tr>
<td>ReSound Smart</td>
<td>0.4</td>
<td>0.25</td>
<td>0.75</td>
<td>0.0</td>
<td>0.078</td>
<td>0.0</td>
<td>0.331</td>
</tr>
<tr>
<td>ReSound Control</td>
<td>0.4</td>
<td>0.25</td>
<td>0.75</td>
<td>0.25</td>
<td>0.68944</td>
<td>0.0</td>
<td>0.387</td>
</tr>
<tr>
<td>miniTek RemoteApp</td>
<td>0.4</td>
<td>0.5</td>
<td>0.75</td>
<td>0.0</td>
<td>0.59584</td>
<td>0.0</td>
<td>0.432</td>
</tr>
<tr>
<td>Test Your Hearing</td>
<td>0.9</td>
<td>0.5</td>
<td>0.75</td>
<td>2.5</td>
<td>0.67424</td>
<td>1.0</td>
<td>0.611</td>
</tr>
<tr>
<td>Hearing Aid with Replay</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.67424</td>
<td>0.0</td>
<td>0.561</td>
</tr>
<tr>
<td>AUD-1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1092</td>
<td>0.0</td>
<td>0.445</td>
</tr>
<tr>
<td>uHear</td>
<td>0.9</td>
<td>0.25</td>
<td>0.75</td>
<td>0.5</td>
<td>0.1092</td>
<td>0.0</td>
<td>0.584</td>
</tr>
<tr>
<td>uSound</td>
<td>0.9</td>
<td>0.25</td>
<td>0.75</td>
<td>2.5</td>
<td>0.67424</td>
<td>1.0</td>
<td>0.611</td>
</tr>
<tr>
<td>soundAMP R</td>
<td>0.9</td>
<td>0.5</td>
<td>0.75</td>
<td>1.0</td>
<td>0.1404</td>
<td>0.0</td>
<td>0.685</td>
</tr>
<tr>
<td>Hearing Help</td>
<td>0.9</td>
<td>0.25</td>
<td>0.75</td>
<td>0.0</td>
<td>0.1092</td>
<td>0.0</td>
<td>0.445</td>
</tr>
<tr>
<td>Weights</td>
<td>0.35</td>
<td>0.3</td>
<td>0.15</td>
<td>0.1</td>
<td>0.05</td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>

scoring is, of course, directly linked to those apps being tailored to particular hearing aid models, which allows for minimal signal processing on the phone (and hence minimum output data creation), i.e. most processing on the hearing aid.

Finally, the remaining apps, i.e. those that do more than just testing and are not aimed at any particular hearing aid model do best, i.e. with scores beyond 50%. This is chiefly explained by high scores in output support, which is to be expected, since these apps are being designed for a particular hearing aid model: For this reason, they are forced to perform the maximum amount of signal processing (and hence of output data creation) themselves, rather than delegating this crucial task to the periphery. soundAMP R with an overall score of less than 50% is an exception here, because of its non-support for profiles at all (if it had the same profiles scores as its 4 peer apps, it would easily reach an equally high score beyond 50%). It has to be said, on the other hand, that none of these five apps even reach a utility of at least 3/4 of the desired functionality. Optimization of these apps in the area of input support would immediately boost most of them to that 75% satisfaction level. To really get close to the 100% utility level, further improvements in per-ear settings are necessary, as well.

The conclusion is: There are certain hearing-aid-independent apps on the market that at least fulfill half of the maximum utility. But their utility is still very far from ideal (100%), and thus still very unsatisfying. Deficiencies in both input and binaural support are the most responsible for this.

5. Summary and outlook

In this paper, classification criteria and their weightings are developed for conducting a cost-utility analysis on state-of-the-art mobile applications with or as more intelligent support for or replacement of hearing aids. The higher goal is to achieve social reintegration in life-critical situations of individuals suffering under hearing loss in an aging society. The classification criteria range from output and input support, certain configuration options and features, down to market shares and general popularity. Their motivations and prioritizations are inspired by the requirements of the related SMARTNAVI project and software examinations. It is possible to demonstrate how the scoring model is applied to a compilation of selected and relevant mobile apps. The results show that even the state-of-the-art is still very unsatisfying and that the improvements necessary are concentrated on input and binaural support for the algorithms. As an outlook and motivation for future work, this points at an urgent support for more sophisticated microphones increased in number (microphone arrays), and a need for multitasking (two signal processing tasks) with more dynamic parameters per process.

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