Listening to Music and Digital Hearing Aids: A Systematic Review

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CERTIFICATE

This is to certify that this dissertation entitled '**Listening to Music and Digital Hearing Aids: A systematic review**' is a bona-fide work as fulfillment for the degree of Master of Science (Audiology) of the student with Registration No. **19AUD023**. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled '**Listening to Music and Digital Hearing Aids: A systematic review**' has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any other Diploma or Degree.

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DECLARATION

This dissertation entitled '**Listening to Music and Digital Hearing Aids: A systematic review**' is the result of my own study under the guidance of **Dr. Manjula. P**, Professor of Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any Diploma or Degree.

Mysuru, **Register No.**

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DEDICATION

*To my parents "**Mr. Victor Khakha & Mrs. Silwanti Baxla",** family, teachers, and to all who supported me during my hard times.*

"You all accepted worst of me. I will give best of me".

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ABSTRACT

Music is a universal language that everyone appreciates and enjoys. It plays an important role in the life of individuals. Millions of individuals listen to music on a regular basis for mood regulation, enjoyment, profession, to complement ordinary tasks (e.g. exercise, transport, home chores), and for social activities (Greasley et al., 2020). A person with a hearing impairment is denied of the pleasures of being associated with music.

The audiological line of management for those with irreversible hearing loss involves use of hearing aids. The hearing aid use is often associated with improved quality of life. An individual with hearing loss will have to rely on hearing aids in order to listen to sounds in the environment, including speech and music. A hearing aid is more efficient in amplifying speech than music. There are several recommendations that have been derived through research in order to improve listening music through hearing aids.

The study aimed at doing a systematic review of the literature related to music and hearing aids since 2020. The literature was reviewed/searched to gather information related to hearing aids and music. The steps followed for systematic review of literature on music and hearing aids included searches in literature, inclusion criteria for literature, data extraction, and quality assessment. Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were used to review the literature. Such a review helps an audiologist to find the information related to hearing aids for music at one place. This also has its role in providing the direction for future research.

The literature implied that CAM2 was better compared to NAL-NL2 for music perception. Further linear hearing aid or WDRC with slow speeds of compression was preferable to faster speed

Chapter 1

INTRODUCTION

Music is a universal language that everyone appreciates and enjoys. It plays a significant role in the life of individuals. Millions of individuals listen to music on a regular basis for mood regulation, enjoyment, profession, to complement ordinary tasks (e.g. exercise, transport, home chores), and for social activities (Greasley et al., 2020). A person with a hearing impairment is denied of the pleasure of being associated with music.

For individuals with a hearing loss, the line of management includes medical/surgical and/or audiological. The audiological line of management for those with irreversible hearing loss involves use of hearing aids and rehabilitation (in case of those with congenital hearing loss). The use of hearing aids has always been associated with improved health related quality of life that also includes, improvement in the social, psychological, emotional and physical well-being of the people.

Hearing aids amplify the sounds in the environment to help the person with hearing loss hear. An individual with hearing loss will have to rely on hearing aids in order to listen to sounds in the environment, including speech and music. A hearing aid is more efficient in amplifying speech than music. Speech and music have similarities as well as differences - in terms of spectra as well as in the perceptual requirements (Chasin, 2003). Speech has a well-controlled spectrum perceptual characteristic that are predictable when compared to music. On the other hand, musical spectra are highly variable and the perceptual requirements can vary based on the musician and the instrument being played. Chasin (2006) has put forth the salient variations between speech and music that have direct implications for hearing aid fittings.

The fact that hearing aids are basically intended for speech rather than music will make listening to music through hearing aids not so desirable. This discrepancy can be attributed to several resemblances and variations between speech and music. The differences are seen in (1) spectral region significance, (2) overall intensities, (3) long-term spectrum, and (4). signal crest factors.

Though the hearing aid amplifies music, the quality of music is affected by hearing aid processing. This is because music is potentially different from speech in terms of its generation and several acoustic characteristics (Arehart et al., 2011). Chasin (2009) identified and reported these differences. They include (1) Overall intensities, (2) long-term spectrum, (3) signal crest factors, and (4) importance of spectral regions.

Hearing aids are basically designed to amplify speech, not music. Chasin and Russo (2004) have reported that music enjoyment through hearing aids is challenging and suboptimal. The quality of music is based on the judgement of the accuracy, appreciation, or intelligibility of the output from a hearing aid. The quality of sounds through hearing aids has been identified as an important factor for hearing aid users (Brennan et al., 2014).

As mentioned earlier, hearing aids have been largely developed for speech rather than music, i.e., music is considered secondary. Outcomes such as speech understanding inventories, mechanism of hearing aids - such as adaptive noise reduction (ANR), wide dynamic range compression (WDRC), and feedback cancellation are primarily developed for improvement in speech understanding (Vaisberg et al., 2019).

There are several prescriptive approaches validated for hearing speech through hearing aids such as, National Acoustic Laboratories-non-linear 1 and 2 (NAL-NL1, NAL-NL2), DSL m(i/o), Cambridge Method for Loudness Equalization 2 (CAM2). All these approaches are developed for optimizing hearing for speech.

Hearing aids are seen as amplifiers which enhance the input to get preferred output. It can be frequency- or level- specific to meet the hearing needs, of the hearing aid wearer, in order to get the benefits of audibility and comfort in this wide range of listening environment. The most commonly known strategy implemented in digital era is wide dynamic range compression (WDRC) which allows the hearing aids to fit the prescribed non-linear targets to achieve the audibility and comfort. Hearing aids deal with varied levels of inputs, low levels or high levels inputs such as music (Chasin, 2016). The WDRC provides more amplification to softer sounds than to louder sounds so that the larger dynamic range could be reduced into smaller dynamic range at the output (Chasin & Hockley, 2014).

NEED FOR THE STUDY

There have been various studies conducted on listening to music through hearing aids Croghan et.al. (2014). Many suggestions are put forth in literature on the features and modifications in the settings of the hearing aids to perceive the music better. The changes are suggested in terms of the features/ characteristics of hearing aids such as directionality, compression knee-point, compression ratios, noise reduction, and feedback management (Chasin & Russo, 2004; Croghan et al., 2014). Thus, there are certain features/ settings in the hearing aids that needs to be set appropriately to perceive and enjoy music. Specific prescriptive procedures are found to be more suitable for listening to music through hearing aids. The findings of these studies are found in different journals and books and the information is spread out. Thus, compiling the available information on music and hearing aids would be beneficial. For an audiologist, information will be available in one place on the best options/ settings available, for making adjustments according to the needs of the clients and to suggest specific settings to make listening to music enjoyable. Further, this compilation serves as a ready reckoner and will also provide directions for future research.

Aim of the study

The study aimed at doing a systematic review and compile the literature related to music and hearing aids.

Objectives of the study

To review the relevant information on music and hearing aids in the following aspects:

1. To explore the literature in order to obtain information on music and hearing aids.
2. To define inclusion and exclusion criteria for seeking information from literature on the topic.
3. To extract data from studies under the inclusion criteria.
4. To compile the literature based on different sub-headings.
5. To present results and assess the quality of evidence.

Chapter 2

METHOD

The steps followed for systematic review of literature on music and hearing aids are provided in the following section. The steps followed include:

1. Searches in literature
2. Inclusion criteria for literature
3. Data extraction
4. Quality assessment

The literature was reviewed/searched to gather information related to hearing aids and music, since 2020. Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Moher et al., 2009) were utilized for reviewing the literature.

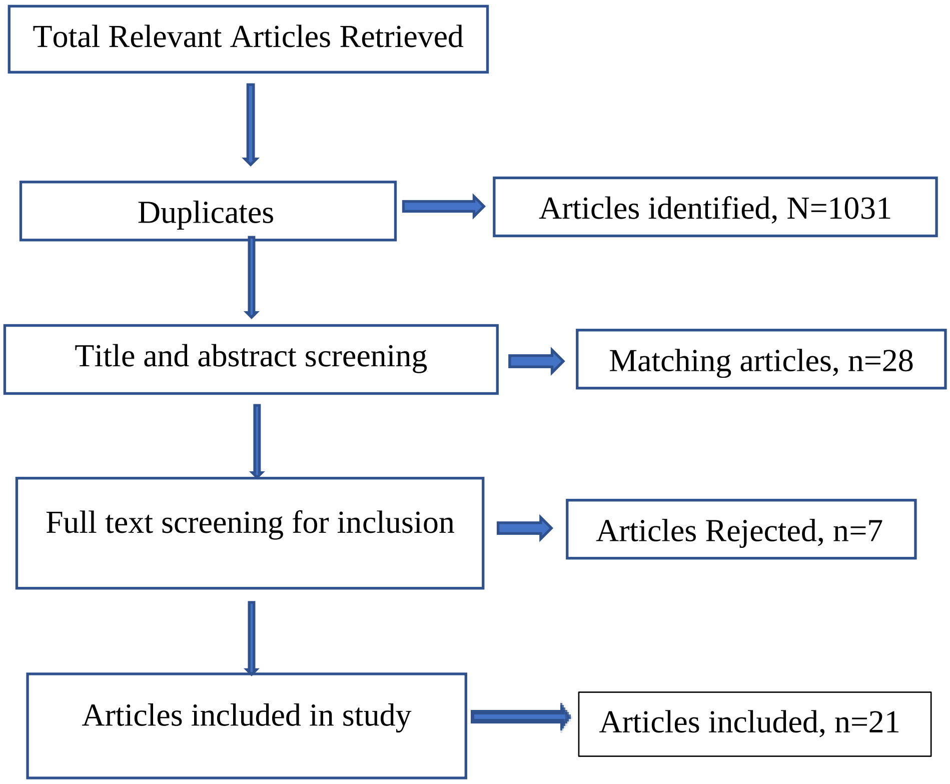
1. Searches in literature

The possible keywords, related search words, their derivatives relevant to the objectives were developed. They included “Hearing Aids” AND “Music” OR “Hearing Aids settings” FOR “Music” OR “Hearing Aids programme” FOR “Music” OR “Hearing Aids characteristics” FOR “Music” OR “Music Performance” WITH “Hearing Aids” OR “Prescriptive procedure” FOR “Music”.

These search words were used in various databases for literature search. The databases included international databases such as PubMed/Medline, Google Scholar, J-Gate, Science Direct, and Com-Dis-dome ProQuest. Attempts were made to include Scopus, Web of Science, Cochrane for literature search. But due to lack of subscription, these databases could not be accessed. Relevant articles/information regarding music and hearing aids was obtained from Google scholar and PubMed only.

The number of relevant articles selected for the systemic review is 21. Prior to arriving at this number, the literature was searched using search words and 1031 articles were identified to match the search words. This is the number after deleting the duplicate articles. From these, in order to obtain the articles with relevant title and abstract, 28 articles were mined. After reading the full text of the 28 articles, only 21 were found to be matching the objectives of the study and hence were included for systematic review. Figure 1 depicts the steps involved in selection of articles for systematic review.

Figure 1: Steps involved in selecting articles for systematic review.



2. Inclusion Criteria for Literature

Literature fulfilling the following conditions were selected:

a) Published in peer-reviewed journals from 2000 to 2021 (August).

b) Article availability in English

c) Articles that included only human participants

d) Participants belonging to both typical and clinical population i.e., those with normal hearing and hearing impairment, hearing aid users.

e) Articles that included instrumental analysis and subjective analysis.

3. Data Extraction (Selection and Coding)

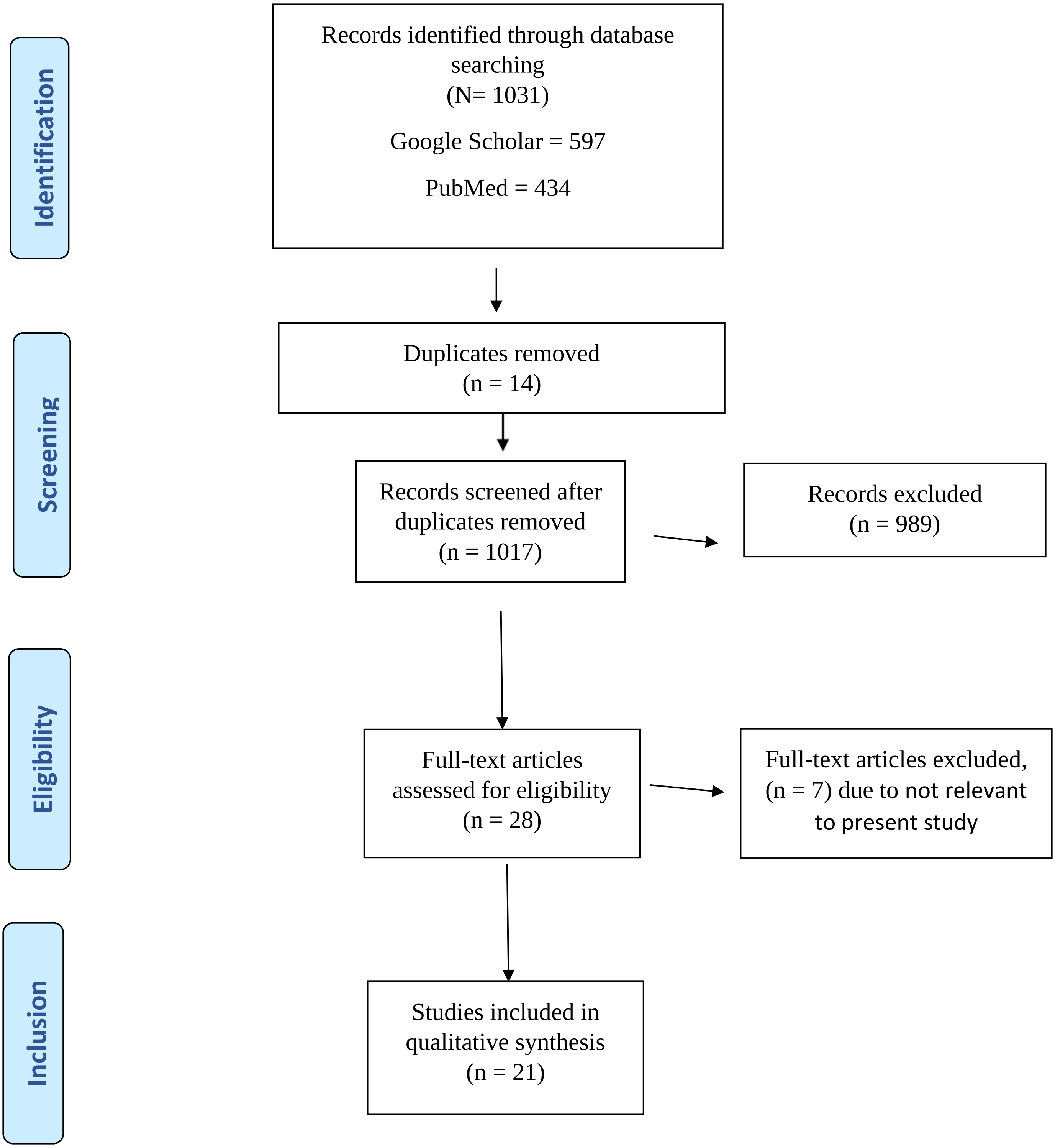
The titles and/or abstract obtained through the search strategies was screened to identify the investigations that met the inclusion criteria. The full text of the potential studies was then retrieved and checked for eligibility.

A standardized, pre-piloted form i.e., Sample form for data extraction (Appendix 1) was developed and used to extract the data from the selected studies. The extracted information included study population, method, participant demographics, data relating to derived measures, assessment procedures and the outcome of the derived measures. In addition, information on year in which the study was published, publication type, study design, research type, focus of research, origin of study and author details with their affiliation were extracted from the eligible studies meeting the inclusion criteria. Studies that reported the data analysis of music without hearing aids or, if music and hearing aids were not included, such articles were discarded.

Results

Literature Selection: A total of 1031 articles related to music and hearing aids were identified using database searches, which excluded 14 duplicates. A total of 1017 articles were selected for the title and abstract screening. From those, 28 articles were selected for full-text screening. Twenty-one (of the 27) articles that satisfied the inclusion criteria were selected for the study. The selection process was validated by inter-judge selection and discussion of disputes. The detailed PRISMA flow diagram for selection of studies was prepared. The details of selection of articles from literature, obtained from various databases, using PRISMA guidelines have been depicted in the Figure 2.

Figure 2: Prisma flowchart for selection of the articles



4. Quality Assessment

Critical Appraisal Skills Programme (CASP) checklist (Critical Appraisal Skills Programme (CASP, 2018; Guyatt, Sackett, & Cook) was used for the analysis of the selected studies. It has 12 questions to analyse the article. Most of the studies identified confounding factors like settings, characteristics of music, types of amplification device used that might have deviated the results and the accounting for the same while analysing the results, if not taken into consideration. However, individuals with hearing impairment, being such a heterogeneous group, with many confounding factors such as, duration, onset, severity, age etc. could affect the outcomes. Such effects were not found in the studies assessed. Also, there are limitations and is not possible to account for and remove all the confounding factors. Information on two of the questions related to follow up was lacking in all the studies. All the studies used standard group comparison design with no longitudinal data. On the whole, the studies showed acceptable results, had good implications for practice and were in line with the other earlier published studies. Hence none of the articles, from the 20 articles, were removed after final qualitative data analysis. Figure 3 depicts the details of quality analyses of these 20 articles

Figure 3: Quality analysis of the relevant articles from literature

Number and availability of reports

From the most popular databases, the results of web search identified only 20 articles reported globally that specifically studied hearing aids and music perception, from 2000 to 2021.

Table 1: Number of articles identified from different databases

Data bases	*Number of articles identified, n=21*
Pub-med / Med-Line	14 (66.7%)
Google Scholar	5 (23.8%)
Google Search	2 (9.5%)
Total	21 (100%)

While performing a systematic review on a specific topic such as hearing aids and music perception, hidden data are a significant drawback. That is research scenario as in the in-house publications remain unknown and inaccessible for other researchers world-wide. The researchers who have the knowledge on the possible centres involved in research on music and hearing aids may specifically look for related literature. But many, including current investigator, might may not find relevant research reports unless it is published on a widely accessible and open database or resource. Also, there exists a large number of databases. Many of them require subscription that is paid. This makes the researcher/investigator in the particular field to hold back from his/her research interest.

This might have resulted in relatively less reported data or literature in the open databases for those interested to look into. Those interested in the field of music and hearing aids should take an initiative and make an attempt to compile the studies through various sources. Most of the openly unavailable source and easily not accessible literature are published within house (Institutional databases) or in local journals that are not indexed. Hence, the researcher also should attempt in developing a good study design/method that could have a good impact on the indexed peer reviewed international journals. Other major contributing factor is limited number of studies found is those that are unpublished or data made available to a limited number of researchers. This can again limit the progress in music and hearing aid research globally. If the research is published this can help in making the research report known for its areas under study, novel methodology and institutions with technologies available along with the researcher carrying out the study. This can increase awareness among and within the professionals (Acoustic Engineer, Audiologists, Speech Language Pathologists, Software developer etc.) which can be beneficial in increasing collaboration between these professionals. These collaborations can help in the development of newer technologies for the management. In order to minimize the wastage of resources such as time and man power, and to enhance the performance in work by avoiding duplications of already conducted research work, openness to research on music and hearing aids is needed. Since access to all available literature is not possible due to reasons such as non-subscription and hidden literature, systematic review of the accessible articles shall provide information related to hearing aid s and music at one place. This will help the researcher to know the area in which research is required.

The reviewed information is also summarized in in tabular so that it forms as a ready reckoner for the reader. After the summary table, the same information is also given in the text format. The salient aspects of related articles have given in detail in the following section. The literature review is categorized under three headings:

1. Prescriptive procedures and music through hearing aids
2. Hearing aid features and Music through hearing aids
3. Other articles related to music through hearing aids

Table 3: Summary of findings of studies on music and hearing aids

Author/s, (Year), Journal name	**Title of the Article**	**Parameters considered under Methods**	**Findings**
Prescriptive procedures and Music through hearing aids			
Higgins et al. (2012)**,** American Journal of Audiology	A comparison between the first-fit settings of two multichannel digital signal-processing strategies: music quality ratings and speech-in-noise scores.	18 participants. Fitting settings of two multichannel digital signal-processing WDRC AND adaptive dynamic range optimizer (ADRO) used. – Stimuli: classic, rock and jazz music.	Participants preferred the quality of music and performed better in QUICKSIN task with hearing ADRO processing. ADRO showed better performance in hearing aid. Because, it has less fluctuation in output with change in sound dynamics.
Moore and Sęk, (2013), Ear and Hearing	Comparison of the CAM2 and NAL-NL2 hearing aid fitting methods	15 participants with sloping hearing loss. CAM2 and NAL-NL2 hearing aid fitting used. Stimuli: (classical, jazz, a man singing, and percussion)	No clear preference. With CAM2 and NAL-NAL2, one showed opposite preference, another showed no clear preference. CAM2 and NAl-NAL2 in context of clarity of speech in noise was present for all stimulus, CS (Compression Speed) & all the levels. Such as flat, reverse-slope, or mid-frequency losses, and also for

			higher degrees of sloping hearing loss.
Johnson (2013), Journal of the American Academy of Audiology	An initial-fit comparison of two generic hearing aid prescriptive methods (NAL-NL2 and CAM2) to individuals having mild to moderately-severe high-frequency hearing loss	Fourteen male veterans, average age being 65 years and whose hearing sensitivity averaged normal to borderline. Prescriptive methods (NAL-NL2 and CAM2) used.	Lack of difference in predicted speech intelligibility between the two prescriptions, sound quality preferences on the basis of clarity were split across participants while some participants did not have a discernable preference. Considering sound quality judgments of pleasantness, the majority of participants preferred the sound quality of the NAL-NL2 (8 of 14) prescription instead of the CAM2 prescription (2 of 14). Four of the 14 participants showed no preference on the basis of pleasantness for either prescription. Individual subject preferences were supported by loudness modeling that indicated NAL-NL2 was the softer of the two prescriptions and CAM2 was the louder. CAM2 did provide more audibility to the higher frequencies (5-8 kHz) than NAL-NL2. Participants turned the 4 - 10 kHz gain.

Brennan et al. (2014), Journal of the American Academy of Audiology	Paired comparison of non-linear frequency compression, extended bandwidth, and restricted bandwidth hearing aid processing for children and adults with hearing loss.	Children (age 8-16 years; n=16) and adults (age 19-65 years; n=16) with mild-to-severe sensorineural hearing loss. Hearing aid with non-linear frequency compression (NLFC), restricted bandwidth (RBW) and extended bandwidth (EBW)	Children and adults did not differ in their preferences. For speech, participants preferred EBW to both NLFC and RBW. Participants also preferred NLFC to RBW. Preference was not related to the degree of hearing loss. For music, listeners did not show a preference. However, participants with greater hearing loss preferred NLFC compared to RBW more than participants with less hearing loss. Conversely, participants with greater hearing loss were less likely to prefer EBW to RBW.
Moore & Sęk, (2016), International Journal of Audiology.	Preferred Compression Speed for Music and its Relationship to Sensitivity to Temporal Fine Structure.	– 16 (10 male, 6 female) – CAM2A and NAL-NL2 fitting method, in a 5channel simulated hearing aid. – Stimuli: Male and female speech, in quiet,	For both compression speeds (slow and fast), CAM2A was preferred over NAL-NL2 for input levels of 65 dB SPL and 80 dB SPL, but NAL-NL2 was preferred at 50 dB SPL. Preferences for CAM2A relative to NAL-NL2 vary with input level. The results suggest that preferences for CAM2A might be increased by using lower gains for high frequencies and low input levels.

		four types of music Input level: 50, 65, 80 dB SPL.	
Hearing aid features and Music through hearing aids			
Davies-Venn et al. (2007), Journal of the American Academy of Audiology	Speech and music quality ratings for linear and non-linear hearing aid circuitry	Eighteen listeners with mild-to-moderate hearing loss was binaurally fitted with behind-the-ear (BTE) hearing aids. peak clipping (PC), compression limiting (CL), and wide-dynamic range compression (WDRC) used. Speech in quiet and noise & 2 genres of music	For speech, WDRC was preferred at 80 dB SPL. Equivalent ratings for all other circuits under other listening conditions For music, preference was for WDRC. Judgements of pleasantness were more influential on overall circuit preference.

Arehart et al. (2011), International Journal of Audiology	Effects of noise, non-linear processing, and linear filtering on perceived music quality	Listeners with normal hearing (n=19) and listeners with sensorineural hearing impairment (n=15). They used NAL-R prescription to fit linear amplification.	Quality ratings in both groups were generally comparable, were reliable across test sessions, were impacted more by noise and non-linear signal processing than by linear filtering, and were significantly affected by the genre of music.
Uys & van Dijk, (2011)**,** The South African Journal of Communication Disorders.	Development of a music perception test for adult hearing aid users.	Normal hearing listeners (n=4) and hearing-aid users (n=20). Music perception test (MPT) for hearing aid users was used.	Adults with normal hearing as well as adults using hearing aids were able to complete all the sub-tests of the MPT, although hearing aid users scored lower on the various sub-tests than listeners with normal hearing. For the rhythm section of the MPT, listeners with normal hearing scored on an average 93.8% and hearing aid users scored 75.5%; for the timbre section the scores were 83% versus 62.3% respectively. Normal hearing listeners obtained an average score of 86.3% for the pitch section and 88.2% for the melody section, compared with the 70.8% and

			61.9% respectively obtained by hearing aid users.
Zakis et al. (2012), International Journal of Audiology	Preferred delay and phase-frequency response of open-canal hearing aids with music at low insertion gain.	Behind-the-ear, open-canal hearing aids were compared in aspects to acoustic delays. (1.4 ms delay and 3.4 ms).	At the 3.4 ms delay, the minimum-phase response was significantly preferred to the linear-phase response for one music sample and vice-versa for the other sample with a sign test ($p<0.04$) but not a Wilcoxon signed rank test that accounted for the low preference strength.
Chasin (2014). Audiology Online	Programming hearing aids for listening and playing music, presented in partnership with the Association of Adult Musicians with Hearing Loss (AAMHL)	Recommendations of hearing aid features for music perception	Clinical strategies include – lowered volume on the input (i.e., lower the signal reaching A/D converter so that the A/D converter can handle without distortion) and increased gain eg. Turn down the volume of a music player, and increase the hearing aid gain. If the music player is turned up, it causes distortion in the front-end processing of the hearing aid. Second tip is to use an FM as input to the hearing aid and then to increase the volume. Microphone attenuator could also be used e.g., Adhesive tape (4-5 layers) in order to reduce the input to the hearing aid for music. Yet another tip is to remove the hearing aid as the music is often louder.

			Other strategies include use of 20- or 24- bit A/D converter instead of 16-bit. Use of low-cut microphone instead of broad band microphone helps in non-occluded hearing aids to perceive the music better. Advanced features can be disabled- noise reduction feature can be disabled. That is, music has +30 to +40 dB signal to noise ratio, hence does not require noise reduction feature enabled. Frequency transposition is not recommended for music through hearing aids. The OSPL90 for music program should be 6 dB lesser than that for speech because, the difference in crest factor of music (18 dB) and speech (12 dB) is 6dB. The overall gain can also be set 6 dB lower than that for speech program.
Croghan et.al. (2014), Ear and Hearing	Music preferences with hearing aids: effects of signal properties, compression settings, and listener characteristics	Experienced hearing aid users (n=18). – linear gain and individually fitted WDRC used.	Acoustic analyses showed that compression limiting (CL) and wide dynamic range compression (WDRC) reduced temporal envelope contrasts, changed amplitude distributions across the acoustic spectrum, and smoothed the peaks of the modulation spectrum. Listener

			judgments revealed that fast WDRC was least preferred for both genres of music (rock and classical). For classical music, linear processing and slow WDRC were equally preferred, and the main effect of number of channels was not significant. For rock music, linear processing was preferred over slow WDRC, and three channels were preferred to 18 channels. Heavy CL was least preferred for classical music, but the amount of CL did not change the patterns of WDRC preferences for either genre. Fast, multichannel WDRC often leads to poor music quality, whereas linear processing or slow WDRC are generally preferred. Furthermore, the effect of WDRC is more important for music preferences than music-industry CL applied to signals before the hearing-aid input stage.

Kirchberger & Russo (2016a), Trends in Hearing.	Dynamic range across music genres and the perception of dynamic compression in hearing-impaired listeners.	Dynamic range of music across genres, effect of CR on music perception.	The dynamic range of speech, based on recordings of monologues in quiet, was larger than the dynamic range of all music genres tested. The perceptual study compared the effect of the prescription rule NAL-NL2 with a semi-compressive and a linear scheme. Music subjected to linear processing had the highest ratings for dynamics and quality, followed by the semi-compressive and the NAL-NL2 setting.
Kirchberger & Russo (2016b), Trends in Hearing	Harmonic Frequency Lowering (HFL): Effects on the perception of music detail and sound quality.	Listeners with hearing impairment (n=19). Age range= 55-80 years. Mean=71 years). Signal processing: Music under different conditions - original, low pass filtered, harmonic frequency lowering (HFL)	Participants reported perceiving the most detail such as detection of instrument, melody, harmony, rhythm in the HFL condition. In addition, there was no difference in sound quality across conditions.

		and non-linear frequency compression	
Moore et al. (2016), Ear and Hearing	Effects of Modified Hearing Aid Fittings on Loudness and Tone Quality for Different Acoustic Scenes	Six participants with normal hearing (n=6; age range being 25-55). CAM2 & NAL-NAL2 fitting with questionaries were used.	Speech in quiet, ratings of loudness with the NAL-NL2 fitting were slightly lower than the mean ratings for participants with normal hearing for all levels (50, 65 and80 dB SPL, while ratings with CAM2B were close to normal for the two lower levels, and slightly greater than normal for the highest level (80 dB SPL). Tone quality was rated as slightly sharper for the NAL-NL2 fitting than for the modified fitting.
Looi et al. (2019), Ear and Hearing	Music appreciation of adult hearing aid users and the impact of different levels of hearing loss	Post-lingually deafened adults (>18 years) who had used their current hearing aids for at least 6 months. Rating questionnaires used.	There were some significant differences noted, between the mild and severe groups, with fewer differences between the mild and moderate groups. Greater levels of HL have a greater reduction on music enjoyment. The hearing aids made music sound less melodic and this was significant.

Greasley et al. (2020), International Journal of Audiology	Music listening and hearing aids: Perspectives from audiologists and their patients	Hearing-aid users (age range: 21–93 years; n=176; mean age: 60.56 years). Music listening questionaries were used.	Sixty-seven percent of hearing aid users reported some degree of difficulty listening to music with hearing aids, and 58% had never discussed music in clinic. 50% of audiologists surveyed asked 1 in 5 (or fewer) patients about music and 67% had never received music-specific training. Audiologist training on music was significantly associated with confidence in providing advice, confidence in programming hearing aids for music, and programming hearing aids for music for a greater number of patients.
Other literature related to music and hearing aids			
Hockley et al. (2010), The Hearing Journal	Programming hearing instruments to make live music more enjoyable	Settings and electroacoustic characteristics of hearing instruments for speech signals, and music. Hearing aids for music lovers may react inappropriately when music is present, since there are many	Music differs from speech and is therefore a potential challenge for hearing instruments. Bernafon Live Music Plus program was found to be useful It uses a combination of elements (Live Music Processing, Channel Free processing, wideband frequency response, fixed directional settings) to present live musical signals accurately to the wearer.

		acoustic differences between speech and music were studies.	
Chasin & Hockley (2014), Hearing Research	Some characteristics of amplified music through hearing aids	Review study (Acoustic properties of music versus speech) Sound levels of music, Spectral shape, Crest factor studied.	Most of the strategies and technologies such as (acoustic properties of music and speech) that have been discussed are related to the finding that most currently available modern digital hearing aids cannot handle the more intense inputs of music within their optimal operating range. Investing in better microphones, amplifiers, and D/A converters will not increase the fidelity of amplified music significantly.
Lundine & McCauley, (2016), American Journal of Speech-Language Pathology	A Tutorial on Expository Discourse: Structure, Development, and Disorders in Children and Adolescents	16 subjects. 13 adults hearing aid users (6 men and 7 women) with bilateral symmetric SNHL were taken. chosen listening levels (CLLs) for recorded music for listeners with	For aided listening, average CLLs were 69.3 dBA at the input to the hearing aid and 80.3 dBA at the tympanic membrane. For unaided listening, average CLLs were 76.9 dBA at the entrance to the ear canal and 77.1 dBA at the tympanic membrane. Although wide inter-subject variability was observed, CLLs were not associated with audiometric thresholds. CLLs

		hearing loss in aided and unaided conditions.	for rock music were higher than for classical music at the tympanic membrane, but no differences were observed between genres for ear level CLLs. The amount of audio-industry compression had no significant effect on CLLs.
Chasin (2016), ENT affairs; (2014), Audiology Online	Music and hearing aids - the current state of affairs	Hearing aid mic, A/D converter; Clinical strategies to improve music through hearing aids	Current technologies (Changing the ‘dynamic range’ absolute values i.e., 96 dB dynamic range for 0 to 96 dB SPL can be changed to 15 to 111 dB SPL., Conditioning the louder music before the A/D converter, Post 16-bit architectures) can handle higher levels of music, as well as the higher levels of a hard of hearing person’s own speech, without distortion.
Vaisberg et al. (2019), Journal of the American Academy of Audiology	A qualitative study of the effects of hearing loss and hearing aid use on music perception in performing musicians	Qualitative Study - participatory needs, effects of hearing aid use, and effects of hearing loss were studied.	Three categories emerged from the data: (1) participatory needs, (2) effects of hearing aid use, and (3) effects of hearing loss. Participants primarily used HAs to hear the conductor’s instructions to meaningfully participate in music rehearsals. Effects of HA use fell within two subcategories: HA music sound quality and use of an HA

			music program. Hearing loss had three distinct effects: inability to recognize missing information, impacted music components, and nonauditory music perception techniques.

The related articles have given in detail in the following section.

1. **Prescriptive procedures and Music through hearing aids**

There are a few studies that have investigated the prescriptive procedures for perception of music through hearing aids. Higgins et al. (2012) compared two digital signal processing methods for multi-channel settings and evaluated for music quality and speech in noisy situations. People prefer hearing aids that work on level dependent digital signal processing approach (DSP) when hearing music and/or taking part in a speech-in-noise. They evaluated two hearing aids - one with 32-channel adaptive dynamic range optimization (ADRO) and the other with dual fast (4 channel) and slow (15 channel) (WDRC). In all cases, the first-fit settings of the manufacturer were used based on an audiogram of the participants. A brief speech-in-noise test (Killion et al., 2004) and three listening conditions were finished in 18 individuals (rock, jazz, and classical). Eighteen individuals were recruited for this study from a voluntary database (13 men and 5 women). All the participants had mild to moderately severe sensorineural loss in high frequency hearing and used hearing aids beforehand. Two of these persons were unilateral hearing loss and were using one hearing aid (HA). Those with conductive hearing loss (air-bone gap >15 dB) were not included. The stimuli were presented twice for each piece of music for each HA type. The initial jazz stimuli and the classical and rock stimuli were played in the same order. According to the results of a QUICKSIN test, participants liked the quality of music and performed better with hearing aids having ADRO.

A research was carried out by Moore and Sek (2013). They wanted to investigate how the hearing aid fitting processes for CAMEQ2-HF (or CAM2) and NAL-NL2. They wanted to use the simulated 5-channel compression hearing aid to compare preference judgement on sound processing with gain and compression ratio (CR) as well as adapting technology such as CAM2 and NAL-NAL2. Fifteen persons having mild sloping hearing loss were included as participants. The speech and music were presented twice, hearing aid with CAM2 settings and with NAL-NAL2 settings. The participant indicated the settings that was preferred for overall quality (for four musical genres were employed as stimuli - classical, percussion, jazz, a male singing) and speech clarity (for male and female speech with speech shaped noise). Variables studied were compression speed (slow/fast) and level of the input sound (50, 65 or 80dB SPL). Nine participants preferred CAM2 to NAL-NL2 for overall quality (this was significant preference for all types of stimuli, both compression speeds, and three levels), while others showed no preference. For speech clarity, five participants preferred CAM2, one showed opposite preference and remainder showed no preference (for all types of stimuli, both compression speeds, all three levels).

Brennan et al. (2014) carried out research to examine whether nonlinear frequency compression (NFC), restricted bandwidth (RBW), and extended bandwidth (EBW) for stimuli (music, words) influenced listener's choice. They examined the way in which adults and children with hearing loss reacted with nonlinear compression with two bandwidths (limited and extended bandwidth) in hearing aids for speech and music. The study included sixteen children (age 8 to 16 years) and seventeen adults (age 19 to 65 years) with mild to severe sensorineural hearing loss. They listened to enhanced stimuli, either 1) reduce the frequency employing the use of non-linear frequency compression, 2) low bandwidth simulation at 5 kHz or 3) low bandwidth at 11 kHz to be used as the simulation of extended bandwidth amplification by round-robin procedure. All the participants heard the speech and music processed by a simulator using an algorithm of Sensation Level 5,0a that was programmed (Scollie et al., 2005).

According to the study results, the participants favoured EBW over RBW, NFC over RBW, and EBW over NFC. It was found that EBW was preferred by participants for speech over the other processing techniques (RBW or NFC), while NFC was better than RBW. The age group between individuals was not statistically important. PTA did not predict speech preference. There was no significant three-way interaction between stimuli, ageing and processing. For music, listeners did not show any preference. The NFC was favoured over RBW among listeners with lower pure-tone average (PTA).

Moore and Sek (2016) examined sound preferences processed by a 5-Channel simulated amplitude compression hearing aid equipped with CAM2A and NAL-NL2 settings. They got sound quality comparisons for four categories of music, silent, masculine voice and feminine voice. The identical sound segments have been delivered randomly, using CAM2A configuration and NAL-NL2 configuration, two times during the trial. Slow and fast compression speeds were used, and the samples were presented at 50, 65, and 80dB SPL. Sixteen individuals (10 males) with wide range of sensorineural hearing loss, between 56 and 87 years of age, were included. They all used compression multi-channel devices.

A variance analysis of the data was done to evaluate the effects of level, speed of compression, and type of signal (four types of music plus male and female speech) on preferences. Speed of compression did not affect the outcome. The type of signal played an important role. CAM2A was favoured for all signals over NAL-NL2, except for the solitary percussion instrument. The energy spectrum is much higher than usual, perhaps making a difference in combination with the larger frequency rises required by the CAM2A. There was considerable interaction between signal intensity and signal type. NAL-NL2 preferences at 50 dB SPL have been best for classic music.

In a study by Johnson (2013), initial fit comparisons were made with 14 Male (average age being 65 years) with normal to borderline hearing sensitivity up to 1000 Hz and sloping to moderately severe SNHL. The comparison was done using National Acoustic Laboratories-Non-linear 2 (NAL-NL2) and Cambridge Loudness Equalization 2-High-Frequency (CAM2) hearing aid fitting approaches. Judgements on their preference for the prescriptive procedures for quality of speech and music were made by the participants.

In addition, each participant made desired prescription adjustments from frequency range of 4 to 10 kHz with overall gain control. After a hearing time of 10 minutes, they performed on the task involving paired comparison of sound quality between the two prescriptions. Majority of the participants favoured the sound quality of NAL-NL2 prescription (8 from 14) over CAM2 (2 of 14). Four out of the 14 participants showed no preference in terms of pleasantness of stimuli.

2. Hearing aid features and Music through hearing aids

In an experiment, Davies-Venn et al. (2007) tested assumptions by evaluating the sound quality of music stimuli from a variety of genres in three distinct conditions, i.e., no compression (linear), full compression (NAL-NL2), and semi-compression. All other compression parameters, with the exception of the compression ratio (CR), remained constant across all circumstances. The study involved 31 listeners with hearing impairment (ages 48–

80, mean age 69 years). There were 20 songs in all (four from each genre: schlager, symphony, pop, choir, and opera).

In this research, the ratings on quality of speech and music stimuli using hearing aid circuits with wide-dynamic range compression (WDRC), compression limiting (CL), and peak clipping (PC) were examined. They asked 18 patients with mild to severe hearing loss who were fitted with two BTE hearing aids (binaural) in order to rate the quality of speech, in quiet and noise, as well as two genres of music. The subjective speech quality evaluations were evaluated using the Speech Intelligibility Rating Test (SIR), which was created by Cox & Moore (1988).

The two-way repeated measures ANOVA was used to analyse the rating ratings for each dimension. For quiet speech, there was no interaction between type of amplification and level of speech for any dimension. However, there was a marginally significant interaction for loudness. The loudness pattern was similar with earlier research (Jenstead et al., 2000), with quiet speech being softer with PC than with WDRC, and conversational or loud speech being louder with PC than with WDRC.

There was no relationship between genre of music and type of amplification in any of the dimensions. The genres were all given the same rating. The type of amplification had no influence on the volume, clarity, or richness of the music. Amplification type had a statistically significant influence on pleasantness and a marginally significant effect on overall impression. For speech, there was a inclination for WDRC at 80 dB SPL, equivalent ratings for the three circuit for all other conditions. For music, WDRC was preferred for classical music. Judgements on pleasantness were influenced by the type of amplification circuit.

In a study conducted by Arehart et al. (2011), the researchers wanted to see how different types of hearing aid signal processing affected music quality evaluations. They used a grading system to measure the musical quality of three different genres of music: jazz instrumental, symphonic classical music, and a female voice. Music stimuli were exposed to a variety of simulated hearing aid processing settings, including (1) linear filtering (2) noise and nonlinear processing, and (3) noise, nonlinear, and linear filtering in combination. The ratings on quality were examined in a group of 19 listeners with normal hearing (NH) and a group of 15 listeners with sensorineural hearing impairment (HI). To ensure stimulus audibility, they utilised NAL-R prescription to match linear amplification to individual hearing loss.

In the NH group, the mean difference in the ratings on quality between conditions with only nonlinear processing and those with mixed processing was 0.20; while in the HI group, it was 0.30. While the quality ratings for nonlinear-only condition were worse than for mixed situations, none of these changes were statistically significant.

The quality evaluations in both groups were largely equivalent and consistent throughout test sessions; however, noise and nonlinear signal processing had a greater influence on them than linear filtering, and the genre of music had a substantial impact. They found that the hearing aid speech quality index (HASQI) predicted music quality ratings pretty well, but they opined that further work is warranted to improve the index for a wide range of music genres and processing circumstances.

Uys and van Dijk (2011) conducted a research with two goals: first, to build a music perception test (MPT) for hearing-aid users, and second, to assess the impact of non-linear frequency compression (NFC) on music perception using the self-compiled exam. The MPT was created in such a way that it could assess many characteristics of rhythm, timbre, pitch, and melody. The MPT's development is divided into phases, each of which is described as design-based. They included the formulation and recording of tests in Phase 1, and the presentation of stimuli to listeners with normal hearing (n=15) and hearing-aid users (n=4) in

Phase 2. Item analysis was done based on the findings of Phase 2 to remove or modify stimuli that resulted in high mistake rates. Several steps were made to enhance the reliability and validity of the modified version of the test, which was done on a smaller sample of normal hearing listeners (n=4) and 20 hearing-aid users (Downing & Haladyna, 2009).

On the rhythm part of the MPT, hearing aid users scored lower than normal hearing users, although they still had reasonably good scores. The investigators opined that the hearing aid users' high scores on the rhythm tasks were not surprising, as it is well known that as hearing loss progresses, individuals with hearing loss become more reliant on temporal cues. This dependence on temporal signals is understandable, given that frequency resolution is lost in most severe hearing impairments, while temporal information is substantially preserved (Flynn et al., 2004).

This suggests that the MPT may be used successfully in the South African setting to measure music perception in hearing-aid users, perhaps leading to more effective hearing aid fits. This test can be used as a counselling tool to help audiologists and patients understand the issue, they're having with music perception. It might also be utilised for future musical training, which could lead to more successful hearing-aid fits. The test may be used as a counselling tool to help audiologists and patients understand their music perception issues, and it might also be utilised for future musical instruction in regions where participants have trouble customising unique fits.

Preferred delay and phase-frequency response of open-canal hearing aids with music at low insertion gain was studied by Zakis et al. (2012). The study suggests that preferences of listeners with normal hearing for low delays and phase-frequency responses of open canal behind-the-ear hearing aids were tested under acoustic circumstances regarded sensitive to delay effects. They had hearing aids fitted at low insertion gain with the three selectable delay and phase response options: (1) 1.4 m/s delay, minimum phase; (2) 3.4 m/s delay, minimum phase; and (3) 3.4 m/s delay, linear phase. With two music stimuli, blind paired comparisons were conducted between processing choices and each option and a muted hearing aid output. "Slightly prefer," "Prefer," and "Strongly prefer" were the three potential forced choice replies. They chose 12 people (6 males and 6 females; range of age: 20-81years). They had sensorineural hearing loss with hearing thresholds of 25 dB HL or more at audiometric frequencies over 1 kHz. They were trained in reading music and participating in music performance.

With a non-parametric test, the minimum-phase response was found to be substantially preferred over the linear-phase response for one music sample and vice versa for the second sample at the 3.4 m/s delay, which accounted for the low preference strength. They came to the conclusion that delays of 1.4 or 3.4 m/s were either undetectable or no worse than no delayed assisted signal condition. With diverse music stimuli, it remained unclear if distinct phase-frequency responses were favoured.

Chasin (2014) put forth certain recommendations for programming hearing aids for music. Clinical strategies include – lowered volume on the input (i.e., lower the signal reaching A/D converter so that the A/D converter can handle without distortion) and increased gain e.g., Turn down the volume of a music player, and increase the hearing aid gain. If the music player is turned up, it causes distortion in the front-end processing of the hearing aid. Second tip is to use an FM as input to the hearing aid and then to increase the volume. Microphone attenuator could also be used e.g., Adhesive tape (4-5 layers) in order to reduce the input to the hearing aid for music. Yet another tip is to remove the hearing aid as the music is often louder.

Other strategies include use of 20- or 24- bit A/D converter instead of 16 bits. Use of low-cut microphone instead of broad band microphone helps in non-occluded hearing aids to perceive the music better. Further, advanced features can be disabled- noise reduction feature can be disabled. That is, music has +30 to +40 dB signal to noise ratio, hence does not require noise reduction feature enabled. Frequency transposition is not recommended for music through hearing aids.

The $OSPL_{90}$ for music program should be 6 dB lesser than that for speech because, the difference in crest factor of music (18 dB) and speech (12 dB) is 6dB. The overall gain can also be set 6 dB lower than that for speech program.

Croghan et al. (2014) recognised the importance of designing and fitting hearing aids to improve music listening. The study's objective was to investigate the roles of characteristics of input signal, hearing aid processing, and individual variability in the perception of recorded music, with a particular emphasis on the impacts of dynamic range compression. A group of 18 experienced users of hearing aid used simulated hearing aids to make paired-comparison preference judgements for classical and rock music samples. Further, audio samples were either unprocessed before being sent to hearing aid or had differing extents of compression limiting (CL). Linear gain and individually fitted WDRC were used as hearing aid conditions. Fast release time (50 ms), long release time (1,000 ms), three channels, and 18 channels were all used in different combinations.

Paired comparisons on the average data. The method described by Rabiner et al. (1969) [and used by Neuman, (2016) and Arehart et al. (2007)] was used to transform the judgements into scores. In this, the total number of times a condition was preferred was divided by the total number of times that condition was given for each listener. Linear processing and slow WDRC had equal preference values, with rapid WDRC being ranked worse in all situations.

Slow WDRC was not substantially different from linear processing while rapid WDRC was considerably less favoured than both linear and slow WDRC. Fast CL led to poor music quality. Linear or slow WDRC was preferred for music. Heavy CL was evaluated lower than moderate CL and no CL, but there was no difference between the two. WDRC had a substantial main effect. Unlike classical music. The interaction between channels and CL was also significant, implying that the channel difference was greatest for heavy CL. For rock music, CL's primary influence was insignificant.

Fast, multichannel WDRC frequently results in poor music quality, whereas linear processing or gradual WDRC are recommended. Furthermore, the impact of WDRC on music preferences is greater than the impact of music-industry CL applied to signals before to the hearing-aid input stage. Frequency resolution abilities may explain some of the variation in hearing-aid users' judgments of music quality.

Kirchberger and Russo (2016a) looked at a frequency-lowering algorithm that had been developed and tested in listeners with hearing impairment. Harmonic frequency lowering (HFL) is a technique for preserving the harmonic content of music stimuli by combining frequency transposition and frequency compression. Listeners were asked to evaluate musical stimuli for detail and sound quality. The research only included people with high-frequency hearing loss who had not previously received frequency-lowering signal processing. Different signal processing settings were used to display stimuli: original, low-pass filtered, HFL, and nonlinear frequency compression. Nineteen listeners with hearing impairment (ages 55–80 years, M1471) were included from Switzerland's hearing aid company’s internal database.

The results of the pre-test indicated that, In the spectral area where the two signals overlapped, the gain weights were defined as the energy difference between the compressed signal and the corresponding original signal. There was no significant main impact of session or segment in the main test, but a significant main effect of condition. The effects of session and segment were not significant in the music quality test. Although the pattern of quality ratings across conditions was more or less comparable with the pattern obtained for the influence of condition was not significant.

Kirchberger and Russo (2016b) investigated an acoustic examination of dynamic range over a cross section of recorded music, and a perceptual research evaluating the efficacy of various compression techniques. The dynamic range of samples from popular genres, such as rock or rap, was typically less than the dynamic range of samples from classical genres, such as symphony and opera, according to the acoustic study. When listening to music, many hearing aid users had issues with their hearing aids, according to a recent Internet-based study (Madsen & Moore, 2014). Many of these issues might be traced to the hearing aid's distortions. Due to the presence of high sound levels and a broad dynamic range (Zakis et al., 2012) claim that live music will frequently cause distortions in hearing aids. The parameterizations differ across hearing-aid manufacturers (Stone et al., 2011), and they may also be affected by the detected signal class, such as speech or music.

They included two experiments. Experiment 1 was on dynamic range of music across genres, and Experiment 2 was on effect of compression ratio (CR) on music perception. The music corpus used for analysis contained 100 songs in each of 10 genres that were opera, chamber music, orchestra, jazz, piano music, choir, rap, pop, schlager, and rock. Results revealed that the percentiles of the modern genres (rock, rap, pop, and schlager) cluster together more than the percentiles of the classical genres (chamber, opera, choir, piano, orchestra), with the extent of clustering in jazz falling some-were in between. Within the classical genres, opera and choir showed higher differences between the highest and lowest percentiles than piano, orchestra, and chamber, especially in region between 0.5 and 2 kHz. The dynamic range of music is generally smaller than the dynamic range of speech in quiet.

Moore et al. (2016) conducted a study to determine the impact of changed hearing aids fits on loudness and time quality for various acoustic scenarios. They chose six normal hearing participants ranging in age from 25 to 55 years old. Standard errors for a particular kind of stimulus and a given level were generally below 0.3 scale units for loudness assessments and below 0.5 scale units for loudness judgements due to the large number of participants. There were 12 participants with hearing impairment (ages 22-84) with normal tympanograms and an ABG of 10 dB or less. Speech in silence (2 male talkers and 2 female talkers) was used as a stimulus, and it was obtained from the recordings of continuous prose reported in Moore et al. (2008). At a speech-to-noise ratio of 0 dB, speech in speech-shaped noise (2 male talkers and 2 female talkers). Classical, jazz, country, pop male, and pop female are the five parts of music. Each stimulus was tested at three different levels: 50, 65 and 80dB SPL.

Participants were asked to assess the loudness of the environment on a rating scale. 1 indicated inaudibility, 2 indicated extremely soft, 3 indicated soft, 4 indicated somewhat soft, 5 indicated comfort, 6 indicated slightly loud, 7 indicated loud, 8 indicated very loud, and 9 indicated painfully loud. Participants were asked to assess the tone quality of each stimulus on a scale of 1 to 9 in the second task, where 1 indicated uncomfortably boomy, 2 indicated extremely boomy, 3 indicated boomy, 4 indicated somewhat boomy, 5 indicated about right, 6 indicated slightly tinny, 7 indicated tinny, 8 indicated very tinny, and 9 indicated painfully tinny. The hearing aid simulator with five channels of compression was employed. The crossover frequencies were 0.7, 1.4, 2.8, and 5.6 kHz, and the centre frequency of channels were 0.5, 1, 2, 4, and 8 kHz. 10 kHz was the upper cut-off frequency. The attack and release timings (ANSI 2003) for all channels were 5 and 10 ms, respectively. In order of increasing the centre frequency, the channel compression thresholds (CTs) were 44,42,40,36, and 40 dB SPL (equivalent diffuse-field levels). The fitting techniques employed were NAL-NAL2 and CAM2.

The results showed that for speech in quiet, loudness ratings with the NAL-NL2 were slightly lower than the mean ratings for normal-hearing participants at all levels, whereas ratings with CAM2B were close to normal at the two lower levels and slightly greater than normal at the highest level. The tone quality of the NAL-NL2 fitting was somewhat better than that of the modified fitting. They came to the conclusion that adjusting gains for different listening conditions might occasionally bring loudness and tone quality closer to "normal." The music-specific adjustment necessary to attain “normal” tone quality had been employed less frequently.

A study conducted by Looi et al. (2019) regarding the impact of different levels of hearing loss on music appreciation in adult hearing aid users. The goal of their research was to gather data on music listening and enjoyment from post-lingually deafened people who used hearing aids (HAs). They also wanted to see if there were any variations in music evaluations between HA users with various levels of hearing loss (HL; mild, moderate to moderately-severe, severe, or worse). This study used a modified version of a previously published questionnaire for cochlear implant patients. It consisted of 51 questions split into seven categories: (1) music listening and backdrop; (2) sound quality; (3) musical styles; (4) music preferences; (5) music recognition; (6) variables impacting music listening enjoyment; and (7) music training programme. Adult HA users were sent the questionnaire, and they were split into three groups: (i) those with a mild HL (Mild group); (ii) those with a moderate to moderately-severe HL (Moderate group); and (iii) those with a severe or worse HL (Severe group). They included participants with no other substantial impairments (e.g., major intellectual or physical impairments); any level of bilateral HL from moderate to profound; and those who spoke English as their primary language. The better ear four-frequency pure-tone average (PTA; i.e., the average of hearing thresholds at 0.5, 1, 2, and 4 kHz of the better hearing ear) was used to determine HL severity; 4 kHz was included to account for sloping HLs.

A total of 111 questionnaires were completed, with 51 people having a light HL, 42 having a moderate to fairly severe loss, and 18 having a severe or greater loss. Respondents with higher HL levels reported a lower degree of enjoyment from music as a result of their HL, and that HAs made music seem substantially less melodious to them. There was no difference between the groups when it came to assessing the pleasantness and naturalness of various musical instruments or instrumental groupings. They came to the conclusion that there was a minimal difference in music appreciation between individuals with mild and severe hearing loss. Those with a severe or worse HL, on the other hand, gave lower appreciation scores. This suggests that HAs or HL have a detrimental effect on music listening, especially as the HL increases.

Greasley et al. (2020) conducted a study on music listening and hearing aids, as well as the viewpoints of audiologists and their patients. Two of them looked at hearing aid users' and audiologists' experiences of hearing-aid use and fitting for music in the United Kingdom. They include the following: A total of 176 hearing-aid users (age range: 21–93 years; mean: 60.56 years) completed a four-item questionnaire regarding music listening problems and clinic talks about music. A 36-item questionnaire was completed by 99 audiologists (age range: 22–71 years; mean: 39.18 years) on the frequency and kind of talks, training received, and techniques for improving hearing aids for music. There were both closed and open-ended questions.

Sixty-seven percent of hearing aid users said they had difficulties listening to music with their hearing aids, and 58 percent said they had never addressed music in clinic. Half of the audiologists polled said they only questioned one out of every five (or less) patients about music, and 67 percent said they had never received music-specific training. According to them, the experiences of hearing-aid users and audiologists with music are still mixed. There is a need for systematic research connecting fitting techniques to clinical results and the establishment of recommendations for audiologist training because there is no formalised training in adjusting hearing aids for music.

3. Other literature related to music and hearing aids

A research on programming hearing aids to make live music more pleasant was conducted by Hockley et al. (2010). Music differs from speech in certain ways, according to Chasin (2003) and, Chasin and Russo (2004). Live music plus and live music processing were evaluated. They utilised wide band frequency response and microphone settings in the compression mode. They concluded that Live Music Plus combines four components to correctly portray live musical signals and enhance the listening experience for hearing aid users. To maintain the dynamic qualities of music, live music processing is used. To correctly enhance music so that it is within the wearer's dynamic range, channel-free processing is used. A fixed directional setting to focus on the playing musicians and a wideband frequency response to assist make the music sound genuine. Nine professional musicians (eight men and one woman) participated in a study in which they were asked to assess how the music they performed sounded to them when they wore hearing aids with Live Music Plus feature.

They inferred that music is very different from speech and so poses a possible problem in hearing. The Bernafon Live Music Plus software combines several components mentioned in the earlier paragraph to correctly display live musical signals to the wearer. Music enthusiasts, whether performers or listeners, may like this programme, according to a trial of this technology including professional musicians.

In a study conducted by Chasin and Hockley (2014), hearing aids were used to research the properties of amplified music. Some of the acoustical distinctions between speech and music are addressed in this review article on hearing aids and music (Cox et al., 1988; Cox & Moore, 1988; Scollie et al., 2005; Keidser et al., 2011). Hearing aids were adjusted to work better for the hearing aid wearer when listening to or performing music, and some modifications and suggestions were made. They claimed that the acoustic properties of music and speech are affected by music levels. Many users of hearing aids seek high quality in amplified music (Chasin, 2003; Chasin, 2006; Revit, 2009;) based on the spectrum assessment of the musical instruments from over 1000 players, the level measurements were conducted from a distance of 3 m on the horizontal plane. When comparing the higher spectral levels of music to those of speech, there were two difficulties that arose. One question was whether music might cause hearing loss in the same way that industrial noise can. Speech, even screamed speech, does not reach a volume that is harmful to one's hearing. The same cannot be true for music, since several studies have shown that long-term exposure to music can result in irreversible hearing loss. (Axelsson & Lindgren, 1981; Royster et al., 1999; Dikranian et al., 2008; Phillips et al., 2008; Schmidt et al., 2011; Poissant et al., 2012).

The long-term average speech spectrum (LTASS) is used to define the spectral characteristics of speech (Dunn & White, 2005). Low-frequency emphasis, high-frequency emphasis, and everything in between are all possible shapes for a music spectrum. While vocal music has a lot of energy in the lower- and mid- frequencies, percussion instruments have a lot of energy in the mid- to high- frequencies.

The American National Standards Institute (ANSI) defines the crest factor for testing hearing aids using a broad-band signal, which is widely utilised in the hearing aid business (Valente et al., 1998). The crest factor was obtained from research on speech levels that utilised 120 msec (Cox et al., 1988) and 125 msec analysis windows (Dunn & White, 2005). The crest factor for speech (12 dB) and music (12 dB) are common values (16-18 dB).

The question was, if hearing aids are built primarily for speech inputs, how well do they perform for music? Hearing aids are first and foremost amplifiers; its principal function is to increase gain to an input in order to produce the desired output. This can be frequency- and level-specific to meet the hearing aid wearer's demands for comfort and audibility in a variety of listening situations. The fitting procedures for hearing aids were linear from the 1940s through the 1980s (Venema et al., 2006). Could volume control operations be automated, or the necessity for it reduced? Compression, also known as Automatic Gain Control (AGC), was used as a technique to automatically change the volume. As the sound level rises, the amount of amplification provided to an input reduces (Hudgins et al., 2005; Steinberg & Gardner, 2005; Ching, Day, et al., 2013). As a result, the fitting algorithms have been changed to be non-linear.

Wide dynamic range compression (WDRC) is the most frequent application of compression technology in the digital realm, and it allows the hearing aid to match the specified non-linear objectives set in terms of audibility and comfort (Keidser et al., 2011; Scollie et al., 2005). Another concern was what hearing aids can accomplish with music as an input source. The tuning for the inner hair cells gets broader when hearing loss affects the outer hair cells (Halpin et al., 2012; Moore & Sęk, 2013). The frequency resolution within the cochlea decreases as the tuning curves expand. Hearing aids, after all, are merely amplification devices that can't yet compensate for the broadening of auditory filters. Frequency lowering devices, which transfer information from an area with the most cochlear damage to a zone where the cochlea can effectively resolve it, might be used to remedy this problem and others involving the loss of inner hair cells (Ching, Day, et al., 2013). However, more study on the impact of alternative frequency lowering implementations on music perception is needed (Uys & van Dijk, 2011; Parsa et al., 2013).

Chasin (2006) reported some techniques for using music as an input with hearing aids users were revealed. Turn down the input and increase the hearing aid volume (Strategy #1). (If necessary). Removal of the hearing aid for music is strategy #2. Cover the hearing aid microphones with tape (Strategy #3). Change the musical instrument as a fourth strategy.

They came to the conclusion that one of the primary limitations of contemporary digital hearing aids was their inability to handle the more powerful parts of music. The A/D converter is the bottleneck. Investing in better microphones, amplifiers, and D/A converters will not increase the fidelity of amplified music significantly. The majority of the techniques and technologies mentioned so far are based on the discovery that most currently available digital hearing aids cannot tolerate more powerful music sources within their optimal working range.

Lundine and McCauley (2016) conducted research on selecting comfort listening levels (CLLs) for music with and without hearing aids. They collected levels of different types of music in both aided and unaided situations, The study included 13 people (6 men and 7 women, age range 21-89 years) who wore hearing aids and had bilateral symmetric SNHL. All of whom had used hearing aids bilaterally. In order to calculate the RMS value, one rock music sample and one classic music sample were obtained for 13 seconds each. The average CLLs for assisted listening were 69.3 dBA at the hearing aid input and 80.3 dBA at the tympanic membrane, according to the findings. For unassisted hearing, average CLLs were 76.9 dBA at the entrance to the ear canal and 77.1 dBA at the tympanic membrane. Despite the large inter-subject heterogeneity, CLLs were not linked to audiometric thresholds. At the tympanic membrane, CLLs for rock music were higher when compared to classical music, but there were no differences in ear-level CLLs.

Chasin (2016) conducted a study on the present condition of music with hearing aids. He concentrated on the wide range of possibilities of contemporary digital hearing aids. According to him, feedback may be successfully handled at the clinical level with the touch of a button on a computer programming screen. Noise reduction algorithms can now suppress the inherent, and sometimes audible, microphone noise. For music noise reduction feature can be disabled since signal to noise ratio is quite high for music. Wireless connection for remote controls and assistive listening devices, televisions, radios, and smartphones are found to be useful to listen to music. The directional microphone patterns can be dynamic and can, in certain cases, seek and remove undesirable background noise.

A 'poorly built front-end' has become a slang term for the problem. The analogue to digital (A/D) converter is a component found in all digital hearing aids. This is the device that digitises a signal and delivers a series of binary integers as an input to a digital algorithm, as the name implies. There may be many A/D converters in hearing aids for different types of input, such as microphone, telecoil, or wireless reception.

Chasin demonstrated a few design options. A number of manufacturers are now using to 18- and 19- bit systems. Although there may not appear to be a significant difference, each additional bit may add another 6 dB to the dynamic range. For a patient who already has hearing aids and is satisfied with them for speech but struggles with music at higher levels, he demonstrated a few tactics: 1. Place four to five layers of tape over the hearing aid microphones. This may seem like an odd clinical treatment, but placing four to five layers of tape over the hearing aid microphones can lower sensitivity by 8-10dB. 2. Turn down the radio volume: Those who listen to music on an MP3 player, the radio, or the television may find this easy solution beneficial. 3. Take off the hearing aid since music is louder than speech: This is especially true for live music and other higher-level inputs. The higher levels of music, as well as the higher levels of a hard of hearing person's own speech, may be handled without distortion by current technologies. The software programme for listening to music is not all that different from the software programme for listening to speech in silence once it has been digitised. The bandwidth, compression, and gain are all unchanged.

A study conducted by (Vaisberg et al., 2019) sought to learn more about the difficulties that adult HA-wearing instrumentalists have in hearing to, responding to, and performing music. They conducted semi-structured interviews with adult amateur instrumentalists as part of their qualitative technique. They gathered data from twelve hearing aid (HA) users who were amateur group instrumentalists (playing instruments from the percussion, wind, reed, brass, and string families) and ranged in age from 55 to 83 years old (seven men and five women). A total of 54 people were contacted and interviewed for this study. A thorough case history was gathered for all participants, as well as pure-tone audiometric thresholds (0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz), word recognition scores at a comfortable listening level, speech recognition thresholds, and tympanometry measures. 49 of the 54 people who took part in the study had some degree of hearing loss (a threshold above 25 dB HL for at least one frequency). 24 of the 49 subjects with hearing impairment had a three-frequency pure-tone average threshold (PTA3) spanning 0.5, 1, and 2 kHz. At least one ear was at 25 dB HL. There were 15 HA users in all, 14 of whom had a PTA3 of.25 dB HL in at least one ear and one who had a PTA3 of 25 dB HL in both ears. An open-ended interview guide was used to conduct semi-structured interviews. Interviews were taped and verbatim transcribed. Traditional qualitative content analysis was used to examine the transcripts.

The findings indicated three categories: (1) participative needs, (2) impacts of hearing aid usage, and (3) effects of hearing loss. Participants generally utilised HAs to fully engage in music rehearsals by hearing the conductor's directions. The effects of HA use were divided into two categories: the sound quality of HA music and the use of a HA music application. Hearing loss had three distinct effects: inability to recognise missing information, impacted music components, and non-auditory music perception techniques.

They came to the conclusion that instrumentalists with hearing impairment had difficulty participating in musical activities. Despite the fact that participants expressed how hearing aids and hearing loss impact music perception, revealing viewpoints on listening utilising the auditory system and other sensory systems, the major motive for their HA usage was the necessity to hear the conductor's orders. These results imply that giving instrumentalists with HI access to musical experience through participation should take precedence over recovering musical descriptor perception.

Thus, from the literature, it could be noted that specific prescriptive procedures, signal processing, features and settings were preferable for perception of music through hearing aids.

Chapter 3

Summary and Conclusions

The perception of music through hearing aids has not been as successful as perception of speech through hearing aids. With the progress of technology, it is necessary to evaluate and know the effectiveness of a hearing aid processing for music perception so that further changes in features/settings can bring about better perception of music through hearing aids.

The CAM2 prescription compared to NAL-NL2, slow compression compared to fast, A/D converter with higher bit processing, ADRO compared to WDRC and compression limiting, lower compression ratio, disabling noise reduction feature are the factors found to improve perception of music through hearing aids. The use of assistive listening devices such as wireless microphone, FM device, streaming help in perception of music.

Future directions

i. Music perception through hearing aids can be studied on individuals with normal hearing. This can be done by recording the output of the hearing aid for various types of music. The hearing aid is to be programmed for different degrees and configurations of audiogram.

ii. Individuals with hearing impairment can participate in a similar research to test music perception by configuring their own hearing aid.

iii. As technology advances, the effectiveness of music perception employing Bluetooth sharing, remote microphone technologies, and radio-frequency sharing music from a device to hearing aid must be evaluated.

iv. Differences in music perception owing to source and environment, such as live vs. recorded, quiet vs. noise circumstances, and room vs. auditorium, can also be evaluated.

v. Technological advancements required to attain similar music perception in virtual and natural environments must be investigated. This may be beneficial to bridge the perception gap, allowing for precise and high-quality music perception with minimum programming modification.

Finally, music is frequently jeopardized due to hearing loss. To improve the individual's overall quality of life, this must be addressed and worked on. Music perception can be improved by making appropriate changes to the settings of various hearing aid parameters. Current technologies/ feature and prescriptive procedures have indicated that WDRC plays an important role as the effect of WDRC is more important for music preferences than CL applied to signals before the hearing-aid input stage. It was noted that using a the NAL-NL2 formula and CAM2 methods help achieve this in the majority of the conditions tested in literature.

Applications of the present study:

1. From this systematic review, information on music through hearing aids was compiled in one place making it easier for an audiologist to find the information.
2. This will help him/her to know about the prescriptive procedures, features and settings to improve perception of music through hearing aids. Thus, helping him/her to serve individuals who enjoy/perform music in a better way.
3. This information will be useful for future directions of research and while programming clients hearing aids for listening to music.

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APPENDIX 1

Appendix I: Sample Form for Data Extraction

<table>
<tr><td colspan="2">Article No:</td><td></td></tr>
<tr><td colspan="2">Name of the Article:</td><td></td></tr>
<tr><td colspan="2">Authors:</td><td></td></tr>
<tr><td colspan="2">Year of Publication:</td><td></td></tr>
<tr><td colspan="2">Journal Published on:</td><td></td></tr>
<tr><td colspan="3">Method</td></tr>
<tr><td colspan="2">1.Types of research</td><td></td></tr>
<tr><td colspan="2">2. Study Design</td><td></td></tr>
<tr><td colspan="2">3.Type of Research</td><td></td></tr>
<tr><td rowspan="3">4. Participants</td><td>a.) Total</td><td></td></tr>
<tr><td>b) Study Group with age range</td><td></td></tr>
<tr><td>c) Control Group with age range-</td><td></td></tr>
<tr><td rowspan="5">5. Procedure</td><td>a) Stimuli used</td><td rowspan="5"></td></tr>
<tr><td>b) Language</td></tr>
<tr><td>c) Instrument used</td></tr>
<tr><td>d) Acoustical Analysis</td></tr>
<tr><td>e) Derived Measures Studied</td></tr>
<tr><td colspan="2">Results</td><td></td></tr>
</table>

APPENDIX 2

Critical Appraisal Skills Program Checklist:

How to use this appraisal tool: Three broad issues need to be considered when appraising a cohort study:

- Are the results of the study valid? (Section A)
- What are the results? (Section B)
- Will the results help locally? (Section C)

Of the 12 questions, the first two questions are screening questions and can be answered quickly. If the answer to both is “yes”, it is worth proceeding with the remaining questions. There is some degree of overlap between the questions, you are asked to record a “yes”, “no” or “can’t tell” to most of the questions. A number of italicized prompts are given after each question. These are designed to remind you why the question is important. Record your reasons for your answers in the spaces provided.

Ref: Critical Appraisal Skills Programme (CASP) part of Oxford Centre for Triple Value Healthcare Ltd www.casp-uk.net

CASP
Critical Appraisal
Skills Programme

Paper for appraisal and reference: ....

Section A: Are the results of the study valid?

1. Did the study address a clearly focused issue?

Yes ☐
Can't Tell ☐
No ☐

HINT: A question can be 'focused' in terms of
- the population studied
- the risk factors studied
- is it clear whether the study tried to detect a beneficial or harmful effect
- the outcomes considered

Comments:

2. Was the cohort recruited in an acceptable way?

Yes ☐
Can't Tell ☐
No ☐

HINT: Look for selection bias which might compromise the generalisability of the findings:
- was the cohort representative of a defined population
- was there something special about the cohort
- was everybody included who should have been

Comments:

Is it worth continuing?

3. Was the exposure accurately measured to minimize bias?

Yes	
Can't Tell	
No	

HINT: Look for measurement or classification bias:

- did they use subjective or objective measurements
- do the measurements truly reflect what you want them to (have they been validated)
- were all the subjects classified into exposure groups using the same procedure

Comments:

4. Was the outcome accurately measured to minimize bias?

Yes	
Can't Tell	
No	

HINT: Look for measurement or classification bias:

- did they use subjective or objective measurements
- do the measurements truly reflect what you want them to (have they been validated)
- has a reliable system been established for detecting all the cases (for measuring disease occurrence)
- were the measurement methods similar in the different groups
- were the subjects and/or the outcome assessor blinded to exposure (does this matter)

Comments:

5. (a) Have the authors identified all important confounding factors?

Yes

Can't Tell

No

HINT:
- list the ones you think might be important, and ones the author missed

Comments:

5. (b) Have they taken account of the confounding factors in the design and/or analysis?

Yes

Can't Tell

No

HINT:
- look for restriction in design, and techniques e.g: modelling, stratified-, regression-, or sensitivity analysis to correct, control or adjust for confounding factors

Comments:

6. (a) Was the follow up of subjects complete enough?

Yes

Can't Tell

No

HINT: Consider
- the good or bad effects should have had long enough to reveal themselves
- the persons that are lost to follow-up may have different outcomes than those available for assessment
- in an open or dynamic cohort, was there anything special about the outcome of the people leaving, or the exposure of the people entering the cohort

6.(b) Was the follow up of subjects long enough?

Yes

Can't Tell

No

Comments:

Section B: What are the results?

7. What are the results of this study?

HINT: Consider
- what are the bottom line results
- have they reported the rate or the proportion between the exposed/unexposed, the ratio/rate difference
- how strong is the association between exposure and outcome (RR)
- what is the absolute risk reduction (ARR)

Comments:

8. How precise are the results?

HINT:
- look for the range of the confidence intervals, if given

Comments:

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9. Do you believe the results?

Yes ☐
Can't Tell ☐
No ☐

HINT: Consider
- big effect is hard to ignore
- can it be due to bias, chance or confounding
- are the design and methods of this study sufficiently flawed to make the results unreliable
- Bradford Hills criteria (e.g. time sequence, dose-response gradient, biological plausibility, consistency)

Comments:

Section C: Will the results help locally?

10. Can the results be applied to the local population?

Yes ☐
Can't Tell ☐
No ☐

HINT: Consider whether
- a cohort study was the appropriate method to answer this question
- the subjects covered in this study could be sufficiently different from your population to cause concern
- your local setting is likely to differ much from that of the study
- you can quantify the local benefits and harms

Comments:

11. Do the results of this study fit with other available evidence?

Yes ☐
Can't Tell ☐
No ☐

Comments:

12. What are the implications of this study for practice?

Yes ☐

Can't Tell ☐

No ☐

HINT: Consider

- one observational study rarely provides sufficiently robust evidence to recommend changes to clinical practice or within health policy decision making
- for certain questions, observational studies provide the only evidence
- recommendations from observational studies are always stronger when supported by other evidence