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Journal of Hearing Science®

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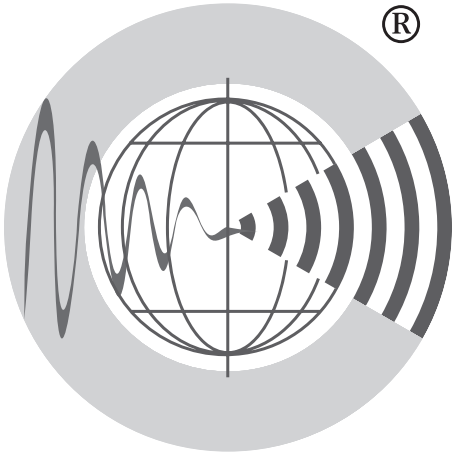

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Dear Colleagues,

We present to you the second issue of the *Journal of Hearing Science* for this year. The issue features a diverse array of articles that underscore the dynamic and multifaceted nature of auditory research and clinical practice.

Our review section opens with a critical examination of mobile applications designed for tinnitus assessment and therapy. As tinnitus remains a challenging condition to manage, this review synthesizes current scientific literature, offering valuable insights into the efficacy and application of mobile health solutions in improving patient outcomes. The second review focuses on the impact of adenotonsillectomy on asthma control in pediatric patients. By systematically analyzing existing studies, this paper provides evidence on the respiratory benefits of this common surgical procedure. It also underlines that further research is needed – with longer follow-up periods, case-matched controls, and consideration of seasonal factors – to improve our understanding of long-term effects.

Among our original articles, we first explore speech perception in noise among Malayalam-speaking young adults with normal hearing. This study adds another dimension to our understanding of auditory processing in diverse linguistic and cultural contexts. Another original study investigates the electrophysiological status of auditory function in noise-exposed, normal-hearing soldiers. This research underscores the subtle yet significant impacts of noise exposure on auditory health, even in individuals who may not exhibit overt hearing loss, showing changes at frequencies outside the standard test range.

The issue concludes with reports from two significant conferences that took place this year. The 15th Danube Symposium of the ORL Danube Society in Budapest, Hungary, and the 8th International Symposium on Meniere's Disease and Inner Ear Disorders in Shanghai, China, brought together leading experts to discuss the latest advancements in otorhinolaryngology.

I wish you interesting reading and thank for your continued engagement with the *Journal of Hearing Science*.

With kind regards and greetings,

Prof. Henryk Skarzynski, M.D., Ph.D., Dr. h.c. multi

Review papers

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TRENDS IN THE ADVANCEMENT OF MOBILE APPLICATIONS FOR THE DIAGNOSIS AND TREATMENT OF TINNITUS: A COMPREHENSIVE REVIEW OF SCIENTIFIC LITERATURE

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Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

Abstract

Introduction: Tinnitus is a condition that requires multidisciplinary care and monitoring. Widespread use of mobile devices and ready access to the internet offers a possible solution since smartphones can run apps programmed for a particular health problem. The aim of the article is to assess the scale and direction of how mobile apps are being created and used to diagnose and treat tinnitus.

Material and methods: Publications in Google Scholar, PubMed, and ResearchGate were searched for the years 2010–2023. The results of the review were organized by themes.

Results: Hits were organized into the following themes: (1) existing mobile apps for tinnitus, (2) apps supporting the diagnosis of tinnitus, (3) apps supporting tinnitus therapy, (4) a look to the future – sensors built-in or connected to mobile devices, wearables, artificial intelligence (AI), and big data systems.

Conclusions: Smartphone-based apps with ecological momentary assessment methods and the possibilities of using wearable diagnostic devices might be useful in better understanding the variability of tinnitus and perhaps its causes. Mobile crowdsensing and central databases with big data and artificial intelligence support appear to be a valuable resource for new scientific research. There are now mobile apps providing a variety of therapies – sound therapy, self-help psychology, and educational training. Equally important for tinnitus therapy are smart devices managed by mobile apps – hearing aids, cochlear implants, and other hearables. In the future, development of mobile technologies and artificial intelligence will help create smart therapy platforms for tinnitus.

Keywords: mobile apps • artificial intelligence • smartphone-based tinnitus treatment • smart devices • ecological momentary assessments

KIERUNKI ROZWOJU APLIKACJI MOBILNYCH W DIAGNOSTYCE I TERAPII SZUMÓW USZNYCH: PRZEGLĄD LITERATURY NAUKOWEJ

Streszczenie

Wstęp: Szumy uszne to schorzenie wymagające wielodyscyplinarnej opieki i monitorowania. Specjaliści poszukują w tym zakresie rozwiązań w coraz powszechniejszym dostępie do Internetu i coraz szerszym wykorzystaniu urządzeń mobilnych. Co więcej, smartfony posiadają ekosystem aplikacji, który można rozszerzyć o nowe aplikacje zaprogramowane pod kątem konkretnego problemu zdrowotnego. Celem pracy była ocena skali oraz kierunku tworzenia i wykorzystania aplikacji mobilnych do diagnostyki i leczenia szumów usznych.

Materiał i metody: Przeszukano publikacje w Google Scholar, PubMed i ResearchGate z okresu 13 lat (2010–2023). Wyniki przeglądu uporządkowano tematycznie.

Wyniki: Rezultaty uporządkowano w następujące kategorie tematyczne: 1) aplikacje mobilne w kontekście szumów usznych obecne w przestrzeni internetowej; 2) aplikacje wspomagające diagnostykę szumów usznych; 3) aplikacje wspomagające terapię szumów usznych; 4) spojrzenie

w przyszłość – czujniki wbudowane w urządzenia mobilne lub z nimi połączone, przenośne urządzenia diagnostyczne, sztuczna inteligencja (AI), systemy gromadzenia dużej ilości danych.

Wnioski: Aplikacje na smartfony z krótkimi chwilowymi ocenami w czasie rzeczywistym i możliwością wykorzystania przenośnych urządzeń diagnostycznych mogą być pomocne w lepszym zrozumieniu zmienności szumów usznych oraz ich etiologii. Gromadzenie dużej ilości danych od użytkowników urządzeń mobilnych oraz ich analizowanie ze wsparciem sztucznej inteligencji to cenne źródło rozwoju badań naukowych. Pojawiają się nowe projekty aplikacji mobilnych prezentujące różnorodną ofertę terapeutyczną – terapię dźwiękiem, samopomoc psychologiczną i treningi edukacyjne. W terapii szumów usznych równie ważne mogą okazać się inteligentne urządzenia zarządzane przez aplikacje mobilne, takie jak: aparaty słuchowe, implanty ślimakowe, wielofunkcyjne smart słuchawki. Rozwój technologii mobilnych i sztucznej inteligencji niewątpliwie przyczyni się w przyszłości do stworzenia inteligentnych platform terapii szumów usznych.

Słowa kluczowe: aplikacje mobilne • sztuczna inteligencja • leczenie szumów usznych oparte na smartfonie • inteligentne urządzenia • ekologiczne oceny chwilowe

Key to abbreviations	
AI	artificial intelligence
AIS	*Athens Insomnia Scale*
CBT	cognitive-behavioral therapy
CI	cochlear implant
conv-TRT	conventional TRT
EEG	electroencephalographic
EMA	ecological momentary assessment
EMAI	ecological momentary assessment and intervention
EMI	ecological momentary intervention
FTRS	Fudan Tinnitus Relieving System
GAD-7	*Generalized Anxiety Disorder 7-item*
GGTI	GGTinnitus app
HADS	*Hospital Anxiety and Depression Scale*
HAs	hearing aids
H-THI	*Tinnitus Handicap Inventory – Hebrew*
JITAIs	just-in-time adaptive interventions
MARS	*Mobile Application Rating Scale*
MCS	mobile crowdsensing
mHealth	mobile health
ML	machine learning
NFB	neurofeedback
PSS	*Perceived Stress Scale*
PSQI	*Pittsburgh Sleep Quality Index*
PTM	progressive tinnitus management
RL	reinforcement learning
smart-TRT	smart device-based Tinnitus Retraining Therapy
TFI	*Tinnitus Functional Index*
THI	*Tinnitus Handicap Inventory*
TQ	*Tinnitus Questionnaire*
TRT	Tinnitus Retraining Therapy
TYT	TrackYourTinnitus (mobile platform)
VAS	*Visual Analogue Scale*

Introduction

Subjective tinnitus is the conscious awareness of a tonal or composite noise for which there is no identifiable corresponding external acoustic source [1]. Tinnitus is considered acute if the patient has experienced it for less than 3 months, sub-acute after 3 months, and chronic if the patient has experienced it for 6 months or more [2]. Tinnitus is not a disease, but a symptom that may occur in the course of various diseases and conditions [3]. Subjective tinnitus may result from pathological neural activity at different levels of the auditory pathway, although the underlying pathology is still not understood [4]. Based on epidemiological studies, tinnitus affects approximately 10–15% of the American population, of which 20% of them consider it a significant problem [5–7]. Research conducted at the Institute of Physiology and Pathology of Hearing, Poland, in 1999–2000 showed that tinnitus is experienced by approximately 20% of Poles over 18 years of age, and 4.8% reported the presence of permanent tinnitus [8].

Tinnitus usually does not pose a threat to the patient, but it can significantly worsen their quality of life and correlates positively with levels of depression, anxiety, and sleep disorders [9–12]. Patients often report variations in tinnitus loudness and severity depending on a range of factors [13–15].

Current recommendations regarding the diagnosis and treatment of patients with tinnitus are included in the following American and European documents: *Clinical Practice Guideline: Tinnitus Executive Summary* from 2014 [16]; *A Multidisciplinary European Guideline for Tinnitus: Diagnostics, assessment, and treatment* from 2019 [2]; and *Tinnitus: Assessment and Management* from 2020 [17]. These reports emphasize the multifactorial nature of tinnitus and the need for a multidisciplinary team for diagnosis and treatment of the condition. According to the above documents, cognitive-behavioral therapy (CBT) is, so far, the best documented scientific method for treating the condition. Hearing aids are recommended for patients with tinnitus who have hearing loss, and improving hearing is an important factor in reducing the severity of tinnitus. The guidelines also refer to neurostimulation methods, which are safe but have not yet been recommended due to the small number of reliable scientific

Table 1. Thematic categories and search criteria in the title/abstract of articles

Thematic categories	Search criteria in the content of the title/abstract
Existing mobile apps for tinnitus available on the internet	mobile/smartphone apps – tinnitus – review mobile/smartphone apps – tinnitus – identification mobile/smartphone apps – tinnitus – analysis – evaluation
Mobile apps supporting diagnosis of tinnitus	mobile/smartphone apps – tinnitus – diagnosis mobile apps – device – tinnitus – diagnosis – validation mobile/smartphone apps – tinnitus – hearing – assessment mobile/smartphone apps – tinnitus – self management
Mobile apps supporting tinnitus therapy	mobile/smartphone apps – device – tinnitus – therapy – treatment mobile/smartphone apps – tinnitus – sound therapy mobile apps – tinnitus – CBT therapy mobile/smartphone apps – tinnitus – self-help –management
A look to the future	mobile/smartphone apps – tinnitus – digital technologies tinnitus – artificial intelligence – machine learning tinnitus – smart therapy mobile health – tinnitus – sensors mobile health – mental health – CBT therapy

studies confirming their effectiveness, and sound therapy methods that are widespread and considered safe, but again cannot be recommended due to the small number of high-quality clinical trials. None of the guidelines recommend drug treatment.

An ongoing goal of research and clinical work is to examine in more detail the factors or ailments that aggravate tinnitus and find ways of better coping with the condition in everyday life [18]. Ways are also being sought to cut waiting times and improve access to reference centers who are called on to provide multidisciplinary diagnostics and therapy. A solution to these problems may be new technologies and rapidly developing mobile networks. Attention is focused on smartphones, which have increasing worldwide reach and more advanced capabilities. Importantly, smartphones have an application (or app) ecosystem into which new apps designed to deal with particular health problems can be loaded.

The use of mobile apps in the health field is constantly expanding into areas of diagnosis and medical interventions. Mobile apps are used for mental health, enabling wide access to therapies that are particularly effective in dealing with depression and anxiety [19]; they can also be used, with the support of AI, to develop rapid and effective screening diagnostic methods for diseases such as cancer [20].

The outbreak of COVID-19 has led to a recognition of the great potential of mobile apps, since rapid, cheap, and easily accessible diagnosis of infection was essential in controlling the disease. Mobile apps and AI techniques were used to identify COVID-19 patients based on a variety of clinical, geographic, demographic, radiological, serological, and laboratory data. In a future pandemic, mobile apps will no doubt play a critical role in rapidly diagnosing infection based on image data and clinical symptoms [21].

The aim of the present study was to assess the scale and direction in which mobile apps are being created and used to diagnose and treat tinnitus, based on a review of the available scientific literature.

Material and methods

Publications in Google Scholar, PubMed, and ResearchGate published in the period 2010–2023 were searched. Thematic categories and search criteria in the content of titles and abstracts are presented in **Table 1**.

Results

Existing mobile apps for tinnitus

An up-to-date overview of existing apps on iOS and Android platforms which can support the management of tinnitus has been presented by Mehdi et al. [22]. The authors identified and described 64 apps categorized into six groups. (1) Tinnitus relief (14 apps) – techniques like masking sounds, relaxing sounds, notched sounds, and acoustic neuromodulation. (2) Cognitive Behavioral Therapy or CBT (10 apps) – mostly not directly related to tinnitus, but dealing with depression, anxiety, and stress which are common psychological comorbidities accompanying tinnitus. (3) Hearing protection (8 apps) – measuring the noise level in the environment or music volume and inform the user about dangerous sound levels, which is important in preventing hearing deterioration and intensification of tinnitus. (4) Hearing testing (11 apps) – testing hearing at different frequencies and in noisy environments; testing the hearing level of children using visual and auditory tasks. (5) Hearing enhancement (10 apps) – amplifying individual sounds based on hearing tests, cutting out ambient noise, supporting auditory attention exercises. (6) Smartphone-based mobile EEG (electroencephalographic) systems (11 apps) – to study real-time brain activity, designed in combination with a handy and mobile dry EEG headset or semi-dry EEG cap; these apps were included in the context of tinnitus because of previous research showing that tinnitus has its own neural correlates. In addition, one of the more popular methods in the alternative treatment of tinnitus is neurofeedback (NFB) – a non-invasive method, generally based on real-time EEG recording, which is presented visually to the patient as positive or negative feedback during training.

Different app rankings have been presented by Mehdi and colleagues in another article [23]. The authors identified 34 apps on iOS and Android platforms, of which 24 were used for tinnitus therapy – the vast majority of them were sound therapy applications which used various sounds – masking, broadband, relaxation, and neuromodulation (with appropriate frequency bands). There were 10 CBT apps, the majority of which were not aimed directly at tinnitus but were helpful in dealing with depression, anxiety, and stress. Among them were three chatbots – conversational agents based on artificial intelligence (AI), whose conversations and advice are based on CBT theory or positive psychology. The average MARS (*Mobile Application Rating Scale*) results calculated on the basis of the mean of four categories (engagement, functionality, aesthetics, and information quality) were assessed on a 5-point scale (1, inadequate to 5, excellent) and ranged from 2.65 to 4.60. These ratings indicate that there were no low-quality apps; all were rated between medium and high quality. However, only 7 of them were backed by clinical research – TinnitusTherapy (Lite), ReSound Relief, SimplyNoise, and Audio Notch as sound therapy apps, and Wysa, Woebot, and MindShift as CBT chatbots [24]. Existing clinical studies on the effectiveness of tinnitus therapy apps have also been described by Nagaraj and Prabhu [25].

The above demonstrates that there are functional and user-friendly mobile apps aimed at dealing with tinnitus, mainly in the field of sound training. Additionally, clinicians and researchers see an increasing need for reliable scientific verification of their clinical usefulness. The scope of tinnitus therapy can be expanded by developing mobile apps with broader therapeutic and diagnostic reach, e.g. in terms of diagnosis, protection, and enhancement of hearing.

Wide access to functional and valuable mobile apps has been confirmed by Deshpande and Shimunova [26]. The authors described the functionality and availability of apps for tinnitus which were available on iOS, Android, and Windows. Both free and paid apps are available on each platform, with a smaller percentage of free apps occurring on iOS (53%) compared to Android (86%) and Windows (85%). Only 8% of apps were available on multiple platforms. A cost-feature analysis revealed that the more expensive apps did not necessarily offer more features. The Android platform had the most tinnitus apps. Among the educational, diagnostic, and therapeutic categories, therapeutic apps dominated, with sound apps predominating both in terms of number and variety of functions. A small proportion of 'misinformation' apps (home remedies, supplements, medically inappropriate strategies) were detected across platforms (5% Android, 3% iOS, 0% Windows).

In 2016, Sereda et al. [27] performed a web survey on 643 respondents suffering from tinnitus in order to examine the extent of use, motivation, and usefulness of mobile apps for tinnitus. The majority of respondents (75%) had never used an app for management of tinnitus, mainly because of lack of awareness of their availability, with 20% saying the reason was that they were not good with technology. These data are from 2016 and the figures will no doubt have changed. In recent years, the level of use of mobile apps by tinnitus patients, their availability and attractiveness, as well as the familiarity with new technology, which is increasingly intuitive, has been growing. The authors noted that in 70% of the apps, sound was the main focus. Other components included relaxation, CBT (dealing with stress and depression), meditation and mindfulness, information and education, hypnosis, and assessment of tinnitus. The authors presented a list of 55 apps that people used for tinnitus (14 of which were developed specifically for the condition). Quality assessment of the 18 most popular apps using MARS resulted in mean scores ranging from 1.6 to 4.2 (out of 5).

Kutyba et al. [28] identified and described 16 sound apps available in the Google Play Store which had the ability to generate different acoustic signals, were free of charge, and were in Polish. Most of them were for relaxation, meditation, and sleep, and only one (ReSound Tinnitus Relief) was specifically designed for people suffering tinnitus. In addition to standard functions such as a sound library, timer, and sound mixer, ReSound Tinnitus Relief includes a set of relaxation exercises and information on tinnitus and available therapies. Kutyba pointed out that all the apps may be useful to a patient as a complement to therapy given by a specialist. Here, it is worth considering the development of understandable instructions for patients with tinnitus on how to use therapeutic and relaxation sounds on a mobile app.

Mobile apps supporting diagnosis of tinnitus

In the area of tinnitus diagnosis using mobile apps, two major directions are apparent. The first relates to self-measurement, i.e. diagnostic assessment of tinnitus or hearing level performed by the patient themself. The second direction is the use of EMA-MCS platforms (mobile crowdsensing platforms based on ecological momentary assessment), which allow tinnitus variability and its accompanying factors to be recorded in real time thanks to self-reporting and automatic data collection using a sensor, smartphone, and app. The data is collected in a central database for research purposes.

Chamoso et al. [29] and Vittorini et al. [30] describe the design of a device and an app for self-measurement of tinnitus using pure-tone audiometry, acuphenometry, and tinnitus severity assessment via questionnaires: the *Pittsburgh Sleep Quality Index* (PSQI), *Khalfa Hyperacusis Questionnaire*, and *Tinnitus Handicap Inventory*. The project consists of a simple electronic device that generates pure tones combined with a headset and bone conduction transducer linked to a mobile app that manages the testing and provides the results. The app gives an assessment of the level of hearing and type of hearing loss, questionnaire results, and tinnitus characteristics. The authors describe the usability tests and improvements made to the tool, as well as the first validity tests, which showed that 25/25 of the app's audiometric test reports were consistent with a standard test performed by a technician.

One step in diagnosing tinnitus involves the diagnosis of hearing level. There are increasing numbers of apps that perform stand-alone hearing tests, most often used for screening or as a way of complementing a standard test. In order for apps to replace the standard examination and

provide effective hearing monitoring outside the clinic (which will enable "just in time" medical intervention), certain conditions must be met, which are described by Handzel and Franck [31]: they include bone and air conduction tests, understanding speech in noise, quiet environment, appropriate masking of the other ear, calibrated headphones, and appropriate sampling (limiting distractions). In mobile diagnostics, this is a developing topic that has the potential to confer many benefits to users and health services.

As previously mentioned, an important issue in the diagnosis of tinnitus as a variable and multifactorial ailment is EMA (ecological momentary assessment) [32,33]. EMA is a real-time measurement of conditions, factors, and symptoms through the use of many short, repeatable assessments, minimizing retrospective bias. Henry et al. [34] and Wilson et al. [35] describe the design of EMA in diagnosing tinnitus using various technological solutions. In Germany, a non-commercial mobile platform called TYT was developed, which serves as the EMA's mobile crowdsensing platform (EMA-MCS), thanks to the collaboration between the Tinnitus Research Initiative and the Institute for Databases and Information Systems at the University of Ulm. Data is collected in a central database, which enables the collection of a large amount of data for research analysis. With real-time research, the dynamics of tinnitus variability can be examined, looking at how the variability depends on various factors (psychological, behavioral, environmental) and allowing a more accurate assessment of their impact to be made than in a retrospective study [36,37]. In preliminary studies, research has indicated that regular use of EMA has no effect on tinnitus annoyance [34,36]. Data in TYT is collected in three ways [36–38]: (1) through registration questionnaires describing the user and their difficulties with tinnitus; (2) through EMA questionnaires containing eight questions completed up to a dozen times a day via set notifications – completing them takes about a minute and relates to various psychological and behavioral dimensions (e.g. stress level, concentration, tinnitus perception, arousal, mood); EMA requires a short, easy assessment, e.g. with the help of a VAS (visual analogue scale) [39]; (3) by acoustic measurement of ambient sounds via the phone's built-in microphone – a future-proof element that makes it possible (although not yet used) to automatically collect various data (environmental, behavioral, physiological) via built-in sensors and connect wearable diagnostic devices or biosensors.

The reference architecture of the TYT platform is described by Pryss et al. [40] and Kraft et al. [41] who also outline its technological development and data management. The TYT platform can deposit anonymized data in a central database, give user feedback, and give results to treating physicians. Based on TYT data, several studies have emerged about the effect of emotional states and their dynamics on the perception and severity of tinnitus [13], and how the variability of tinnitus depends on time-of-day [14]. Research has also confirmed the value of a prospective study [15], from which it is apparent that (1) the variability of tinnitus tested prospectively using EMA was noticed even in those people who did not notice it retrospectively; and (2) the level of stress correlated positively with the severity of tinnitus in the EMA test, even in those people who did not notice the relationship retrospectively. First predictions using machine learning on a large amounts of data from TYT have been described by Breitmayer et al. [42], Allagier et al. [43], and Pryss et al. [44]. Notably, Breitmayer found, based on a data set of 45,935 responses and using different machine learning techniques, that the presence of tinnitus could be predicted with an accuracy of up to 78%, with an area under the curve as high as 85.7%.

The above research indicates the possibility of widening the availability of diagnostics by using efficient self-measurement methods. It also indicates how new diagnostic and predictive models of tinnitus and comorbidities can be created by collecting and analyzing large amounts of data using EMA, MCS, and AI techniques.

Mobile apps supporting tinnitus therapy

The previous section on identifying mobile apps for tinnitus found that there was a clear dominance of apps offering sound therapy in various forms. The main motivation for using such apps was to use sounds to mask tinnitus, to relax, and to fall asleep more easily. Clinicians are now discovering the possibilities of also using mobile apps for more complicated sound therapies, such as acoustic coordinated reset neuromodulation therapy for tinnitus. Hauptmann et al. [45] presented an experimental system based on a mobile app that supports manual and adaptive tinnitus pitch and loudness matching, creation of therapy signals, transfer of the signals to a mobile device, programming the mobile device, recording of patient responses, and presentation of outcome measures. The authors confirm that mobile devices are able to reliably and accurately deliver acoustic therapy signals. For therapy, a mobile device can be operated independently and effectively by the patient after a short initial training. Even though the patient operates independently, the treating physician can constantly monitor how therapy is progressing: therapy compliance is documented within the mobile device and transferred to the clinician's computer, where the clinician can analyze and solve emerging difficulties.

Beyond using sound therapy, it has also been noted that users are seeking additional forms of support in managing tinnitus. Apps have begun to appear that supplement sound therapy with additional elements such as education and psychological training.

Evaluation of the effectiveness of tinnitus sound therapy apps, alone or in combination with other elements, are presented in **Table 2**. This work largely confirms that mobile apps can be an effective tool to reduce the severity of tinnitus while being cost-effective and easy to access. However there is still a need for the efficacy of these apps to be explored in large randomized controlled clinical trials.

An example of a mobile application that is CE marked and was placed on the market as a medical device in 2019 in German language is Kalmeda Tinnitus app. The app consists of 5 levels with nine steps each. Levels 1 and 2 of the behavioral therapy (areas redirecting attention, relaxation) are typically completed in 3 months. Subsequent

Table 2. Evaluation of the effectiveness of tinnitus sound therapy apps, alone or in combination with other elements, based on selected research

Study	Rehabilitation strategy	Population	Outcome measures	Efficacy of rehabilitation strategy
Kim et al. [46]	Smartphone app, delivering notched music therapy for 30–60 min per day in a quiet environment and ginko combined treatment for 3 months. Duration and frequency of app usage were saved on the server and could be checked by the physician.	individuals with chronic tinnitus ($n = 26$)	1. THI 2. VAS – perceived tinnitus loudness, noticeable time, annoyance, effect on daily life.	THI scores improved significantly ($p = 0.03$) after treatment, especially emotional component.
Tyler et al. [47]	Sound therapy provided by the ReSound Relief app for CI patients. Sounds were streamed from an iPod to the CI using a Cochlear Wireless Mini Microphone 2+. Laboratory trial: matching the sound, listening to it for 5 min, assessing the effectiveness and acceptance level of the sounds. Home trial: listening to selected sounds at home for 2 weeks.	CI (Nucleus 6 processor) users with tinnitus: laboratory trial, $n = 13$; home trial, $n = 10$	Laboratory trial on a scale of 0–100: – tinnitus loudness – annoyance of the tinnitus – sound acceptability Home trial on a scale of 0–100: – tinnitus loudness – overall effectiveness of sound therapy.	Laboratory trial: all 13 participants had lower ratings for tinnitus loudness. Home trial: the overall effectiveness of sound therapy 3 of 10 rated 70% or higher, 6 of 10 from 30% or higher.
Sabarish, Kurthika [48]	Sound therapy provided by the Tinnitus Therapy Lite app for 45 min a day for 1 month without changing previously made settings (sound and volume selection). Regular follow-up of usage done every 5 days.	individuals with tinnitus ($n = 5$): 4 with hearing normal and 1 with bilateral mild sensorineural hearing loss	THI	There was a decline of at least 18 points in THI scores for all participants.
Kutyba et al. [49]	Sound therapy provided by the ReSound Tinnitus Relief app for at least 30 min a day for 6 months: self-selected sound, quieter than your own tinnitus, used in a silent environment, before bedtime or when tinnitus disrupted daily tasks.	individuals with chronic tinnitus ($n = 52$)	1. TFI 2. THI 3. App usage assessment survey (after 3 and 6 months from starting sound therapy).	Clinically significant improvement declared: – after 3 months 11.5% of users (THI), 27% (TFI) – after 6 months 53.8% of users (THI), 58% (TFI). App easy to use – 86.4%. Liked to use the app daily – 73%.
Abouzari et al. [50]	Tinnitus-specific CBT and personalized and frequency-matched sound therapy provided by the app for 8 weeks: 2 h daily listening to the sound and 2–3 h weekly on CBT modules.	individuals with chronic, constant bilateral, non-pulsatile tinnitus ($n = 30$): 20 in treatment group and 10 in control group (waitlisted)	1. THI 2. GAD-7 3. PSS	The two cohorts had similar changes in GAD-7 ($p = 0.07$) and PSS ($p = 0.34$). The treatment group had a significantly higher improvement in THI scores (17.2 vs 5.3, $p = 0.04$).
Tang et al. [51,52]	Using FTRS app, patients were recommended to listen to tailor-made music for > 2 h a day (with headphones or speaker) and fill in self-help questionnaires on the app at baseline, after 1 month, and after 2 months of treatment. FTRS provides a large amount of data for clinical research.	users of the FTRS app: $n = 2744$ at baseline $n = 54$ at 2-month follow-up	1. THI 2. HADS 3. AIS	The scores of THI (51.5–33.8), HADS-A (6.93–4.56), HADS-D (6.38–3.78), and AIS (7.65–5.92) were significantly improved at 3-month follow-up compared with baseline. There were significant negative correlations between the scores and follow-up time for THI.

Table 2 continued. Evaluation of the effectiveness of tinnitus sound therapy apps, alone or in combination with other elements, based on selected research

Study	Rehabilitation strategy	Population	Outcome measures	Efficacy of rehabilitation strategy
Engelke et al. [53]	Structured counseling combined with sound therapy provided by the app in two phases: – baseline phase (tinnitus symptoms were measured daily (min 7 days) using app-based EMA using 10 VAS questions; – intervention phase: 12 weeks of daily sessions of structured counseling, sound therapy (at least 15 min per day) and EMA.	individuals with chronic tinnitus indicating at least a mild tinnitus handicap ($n = 21$)	1. THI 2. EMA module via app – 10 VAS questions – an end-of-day diary to track changes in tinnitus symptoms evoked by the intervention. A randomized multiple-baseline design across groups was used.	The mean THI was improved by 11.8 points ($p < 0.001$). 72% of patients had meaningful clinically improved THI scores (THI ≥ 7). Positive relationship between tinnitus distress and loudness weakened over the course of the study.
Suh et al. [54]	Smart-TRT was compared with conv-TRT. Smart-TRT: directive education; 3 interactive smart pad applications (numerous video clips, 1 a month) and sound therapy (white noise via smartphone at least 6 h a day). Conv-TRT: 3 sessions of counseling (1 a month) provided by a single clinician and sound therapy.	individuals with chronic tinnitus ($n = 84$): 42 in smart-TRT group and 42 in conv-TRT group	1. THI 2. Four VAS questions (awareness of tinnitus, annoyance, loudness of tinnitus, effect on daily life)	In both groups THI scores improved significantly over time ($p < 0.001$). There was no difference between the groups ($p = 0.76$). In both groups the VAS scores improved significantly over time in awareness, annoyance, effect on daily life.

levels 3–5 deal with the areas of mindfulness, acceptance, self-efficacy and are typically completed in not less than 7 months. Exercises are complemented by soothing nature and background sounds, guided meditation, and tinnitus related information [55]. Walter et al. [55] tested its safety and effectiveness in 187 patients with tinnitus in a randomized controlled trial. Tinnitus related distress and associated burdens (depression, stress) was significantly decreased in the intervention group compared to the control group. The results indicated significant reductions of TQ (*Tinnitus Questionnaire*) sum score in intervention group: -13.36 ± 1.00 compared to control group: -0.63 ± 0.98; $p < 0.0001$.

An interesting therapeutic project using a mobile app was presented by Henry et al. [56]. The authors developed and tested the Tinnitus Coach mobile app, which supports learning and creating individual coping strategies based on PTM (progressive tinnitus management). Users were given access to various functions, e.g. the opportunity to independently identify problematic situations and create coping strategies for it (Add & Use Plans); they also had access to quick sources of help in the form of sounds and relaxation trainings (Sampler) and short articles on topics related to tinnitus in general, as well as to the coping skills offered by the app (Learning Nook). Henry and colleagues found that users were more likely to use ready-made solutions prepared in the app than tasks requiring the self-creation of coping strategies.

Other projects of tinnitus education and psychological therapy via smartphone apps have recently appeared which involve working with the app using intuitive and simple tasks [57,58]. The first, by Schlee, developed and explored the feasibility of an educational training app (Tinnitus Tipps App) containing 108 self-help tips given every day for 4 months. Based on their research, the authors pointed out that frequent and intensive use of the app is crucial for treatment success – participants that used the app more often and interacted with it intensively had a stronger improvement in tinnitus. The second, by Oron, was an open pilot trial of the effectiveness of the GGTinnitus app (GGTI), a CBT-based program of 48 levels of short quests that aim to change maladaptive, catastrophic beliefs. Participants are asked to train for a few minutes daily, preferably before sleep, in order to consolidate memory and are advised to complete the tasks in 16 days. Of the 14 participants taking part, only 2 did not experience any reduction in H-THI (*Tinnitus Handicap Inventory – Hebrew*) score.

In terms of projects that are encouraging, pleasant, and encourage independent therapy for tinnitus, the "serious game" concept described by Schrickler [59] is interesting. It is an idea for a virtual game that in the context of tinnitus aims to suppress irrelevant sounds by focusing on target sounds and ignoring the background. Specifically, the user must detect target animal sounds from a background, e.g. similar to sounds on a farm or similar to their own tinnitus. Compared to traditional hearing training, its advantages are that it can be played at any time, is enjoyable, provides immediate feedback, and can be steadily increased in level of difficulty, raising motivation and learning.

Demoen et al. [60] have described an approach where the mobile app does not completely replace the therapeutic program, but complements and continues it, an approach that may reduce treatment costs. The protocol

they describe is for a randomised controlled trial which aims to gauge both the effectiveness and cost of a mixed physiotherapy and counseling program for somatic tinnitus using an app. The experimental group receive the blended physiotherapy program comprising six in-clinic physiotherapy sessions over a period of 12 weeks (1 every 2 weeks) as well as an exercise and counselling program provided by an app. The control group receive the standard care program comprising 12 weekly in-clinic physiotherapy sessions.

An example of using a chatbot within a mobile app has been presented by Bardy at al. [61]. The authors performed a randomized, 2 parallel-group trial to compare the clinical effectiveness of iCBT delivered only through a chatbot mobile app (Tinnibot) and iCBT delivered through a Tinnibot together with telepsychology (with the assistance of a video-psychoeducational psychologist). The intervention period was 8 weeks, with assessments at pre-intervention, post-intervention, and 2 months follow-up. The study showed that, 16 weeks after the start of the iCBT program, over 60% of participants in both groups (Tinnibot only or hybrid intervention with telepsychology), showed a clinically significant decrease in tinnitus distress. The addition of telepsychology might be beneficial, but not essential for the effectiveness of the treatment. Tinnibot incorporates traditional CBT practices of identifying and challenging negative thoughts, activating behavior, training in relaxation, mindfulness, acceptance, and gratitude, and creating environments containing relaxing sounds.

An important factor in the use of mobile apps for self-help is the user's motivation – to complete the proposed therapy and make the most of what the app offers and to regularly feed in data that helps with research and therapeutic outcomes. The studies mentioned earlier indicate that there is quite a high percentage of test subjects who disqualify themselves at an early stage of the study due to failure to complete the therapy, technical difficulties, omission of complete answers, or losing contact [49,51,57,58]. At the same time, researchers often emphasize the relationship between the effectiveness of therapy and the frequency and time spent on it [49,51,57]. There is therefore a need for further research into factors that will make an app's functions more attractive and intuitive so that the user is more motivated to use it. Clinicians can play an important role here by helping to match an app's features to the patient's needs and by monitoring the course of therapy. We think that specialists dealing with the diagnosis and treatment of tinnitus should familiarize themselves with what apps exist, as well as their functions and effectiveness, so that appropriate solutions can be proposed to their patients.

A look to the future

Searchfield et al. [62] describe four generations of technological and digital development of tinnitus therapy, with the fourth the current generation of AI, hearables, biosensors, and wearable technology.

AI in mHealth means analyzing and learning from huge amounts of data through ML (machine learning) and RL (reinforcement learning) to create new diagnostic paths, new models, and profiles of different health ailments [18]. The review by Milne-Ives et al. [63] shows the diversity and feasibility of using AI to support mobile apps for mental health in a variety of ways, e.g. for prediction of mood and stress, for natural language conversations, and for delivery of notifications. The importance of AI is also emphasized in optimization of just-in-time adaptive interventions (JITAIs) and ecological momentary interventions (EMIs) – personalized interventions in a person's daily life, given at the right time, based on real-time assessment. In this way, JITAI adapts contextually to the changing internal state of the individual [63–67]. The distinguishing feature of JITAI compared to EMI is the use of statistical methods to improve and tailor interventions over time for a given individual [66]. The development of EMI and JITAI, based on mobile data collection technologies (e.g. sensors, wearables, powerful computational capabilities of smartphone), is currently accelerating in the area of mHealth, including psychotherapy and behavioral approaches to dealing with depression, anxiety, stress, and addictions [65–67]. Designed interventions may involve both the delivery of interventions automatically via a mobile app and delivery of just-in-time support by the doctor/therapist based on data provided by the app [66]. Intervention content can be delivered in various ways – as notifications, text messages describing tasks to be performed, visual and audio images, conversational interventions (chatbots), and activation of a support network [66]. Algorithms can be included that change the settings of a therapeutic device, e.g. hearing aid, cochlear implant, sound generator, depending on the stream of delivered data.

The possibilities of using ML algorithms are increasing in the field of medicine. Manta et al. [68] described a study using ML for tinnitus diagnosis based on wavelet-transformed auditory evoked potential signals and clinical data. The first mentions of using ML on large amounts of data from TYT can be found in Breitmayer et al. [42], Allagier [43], and Pryss [44]. Interesting developments have been presented by Doborjeh et al. [69], where the authors demonstrated the potential use of AI algorithms to predict tinnitus therapy outcomes based on EEG data. Neural networks were used to model frequency features of the EEG and functional connectivities, giving up to 99% accuracy for predicting whether patients would be responders or non-responders to sound-based therapy. The authors point out that this is the first step towards creating a real-time prognostic digital health system based on a small number of EEG variables from a wearable device that a patient could use at home.

Another possibility for use of AI in mobile apps are chatbots. Chatbots are conversational guides/therapists based on AI that could be used in medicine and psychology to analyze patient data in a real time and suggest relevant solutions. Assessments of their effectiveness was described by Moulya and Praghathi [70], Karkosz et al. [71], Klos et al. [72], Pryss et al. [73], Gutu et al. [74], and Fulmer et al. [75]. Chatbots in a therapeutic mobile app could be used as guides, verbally suggesting certain steps or solutions, or they could recognize emotions, verify the user's current needs, or propose, in a conversational form, specific therapies (such as CBT, motivational dialogue, positive psychology, etc.).

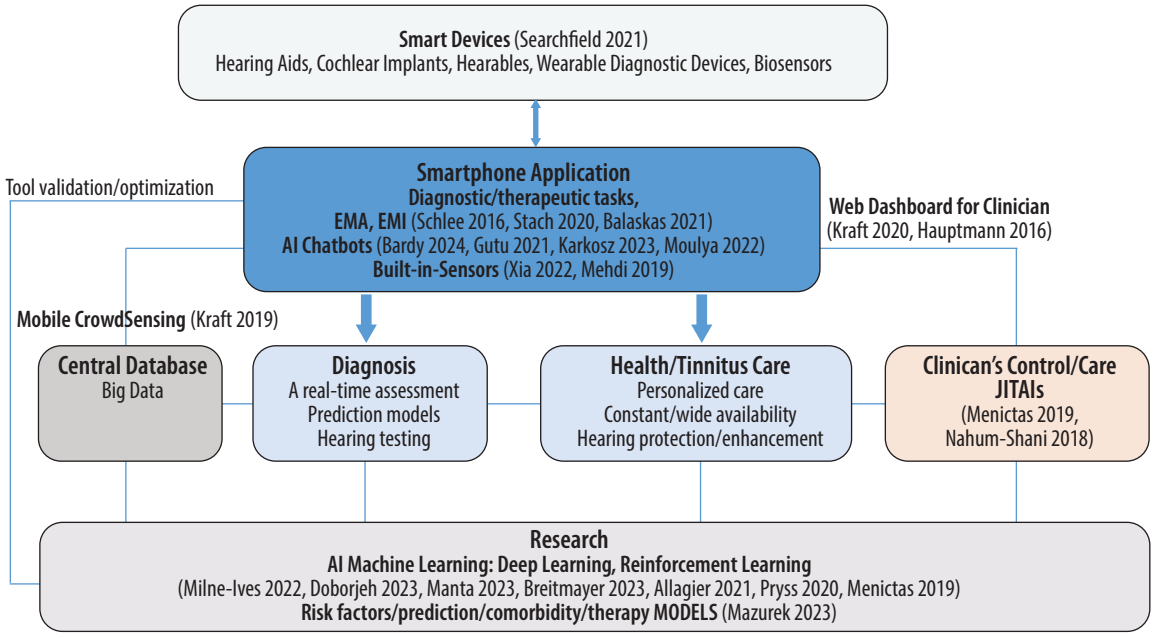

Figure 1. Directions and technological background in the development of smartphone apps for tinnitus diagnosis and treatment

The increasing prevalence of smart mobile devices and apps enables the combined use of mobile crowd sensing (MCS) and ecological momentary assessments (EMAs) in the healthcare domain. Moreover, the combined use of MCS and EMA increasingly requires appropriate architectures and associated digital health solutions for the collection and management of large amounts of data. A reference architecture for the EMA-MCS platform with development directions and potential uses was described by Kraft et al. [41,76].

Sensors built in, or connected to, mobile devices are important in developing effective mobile diagnostics and therapy [77]. There are recent examples of how sensors can be built into smartphones for tinnitus treatment. Mehdi et al. [78] presented the Tinnitus Sense mobile app project, which aims to study the relationship between weather factors and the severity of tinnitus: weather data is collected automatically using smartphone sensors and visualized and managed by the app. Kraft et al. [76,79] presented a crowd sensing platform collecting a large amount of automatic data from sensors in smartphones in order to map areas with different noise levels, a facility that might help tinnitus patients avoid places with high noise levels.

Together with various miniaturized wearable diagnostic devices, sensors enable automatic collection of various biological, behavioral, and environmental data in real time; they can then make longitudinal measures of physiological functions that can be associated with the severity of tinnitus [62]. Nevertheless, attention needs to be paid to technological challenges, data protection, and anonymization, and the costs of carrying out this type of measurement [80].

Mobile apps are becoming increasingly popular in the control and management of smart devices for hearing and tinnitus therapy such as hearing aids (HAs) and cochlear implants (CIs). Searchfield et al. [62] describe the importance of rapidly developing technologically advanced smart hearing aids, cochlear implants, and smart headphones (hearables) in tinnitus therapy. HAs are used in tinnitus management to reduce the accompanying hearing handicap, reduce the attention paid to tinnitus, provide sound therapy, and raise the level of environmental sounds so that tinnitus can be effectively masked. Tinnitus sound therapy strategies developed for HAs are also being trialed with CIs. In the future, smart headphones with multiple functions (hearables) could be used as an alternative to HAs. Searchfield, referring to recent publications on the development of smart devices, noted that efforts to develop cognitively controlled HAs and ear-based EEGs could be extended to tinnitus treatment, with real-time adjustment based on AI [62]. The real promise of this technology is the potential to combine biometrics (e.g., EEG, heart rate, temperature, skin resistance, blood oxygen, and stress hormone levels) with auditory or other sensory stimulation.

Figure 1 summarizes the directions and technological background in the development of smartphone apps for tinnitus diagnosis and treatment. Appropriately combined, these possibilities may create the smart diagnostic and therapeutic platforms of the future. The platforms could offer personalized prediction models based on a real time assessment with AI support, as well as personalized care with constant and wide availability and just-in-time interventions.

Challenges and directions for future research

The systematic development of mobile technologies, including remote monitoring of a patient's health, will lead to innovative diagnostic and therapies with significant potential for health care systems.

Wide and constant access to diagnostic and therapeutic techniques, effective management of chronic diseases, and support for therapeutic decisions via mobile technologies are important developments in audiology. However, existing work in the field of self-measurement of hearing and tinnitus still need to be optimized, verified, and clinically proven before effective diagnostic methods can be introduced. In the area of diagnostics, then, a key factor is the scope and accuracy of self-measurement when used for the subjective and objective assessment of hearing. A similar comment relates to the assessment of the condition of the middle ear using modular portable devices together with a smartphone and a mobile app. Adapting these solutions to specific patient groups (e.g. older people) is a major consideration.

An important direction of research in audiology is the development of EMA methods. These will allow better control and management of chronic ailments such as tinnitus, in particular its progression, and how hearing levels improve or fluctuate as the result of various factors or use of therapeutic methods. The option of being able to have a reliable self-measurement, performed by the patient in real time and in natural conditions, might help create better predictive and diagnostic models. It will also enable more timely therapeutic responses during the course of tinnitus treatment. Just-in-time medical check-ups will not only increase the quality of therapy, but might also reduce treatment costs. Further research in this area will need clinically verified, accredited portable diagnostic tools for collecting automatic data (physiological, behavioral, environmental) in real time. The challenge will be to reduce the costs of these devices, adapting them for everyday use, taking into account patient motivation and eliminating technological and economic barriers (cost, access, and bandwidth). These solutions will require the creation of databases collecting large amounts of self-reported and automatic data of high quality. The challenge is to organize effective multidisciplinary cooperation in creating platforms to collect data, and then make it available to researchers, doctors, and patients. Legal regulations regarding the collection, management, and protection of sensitive data in these new systems will be an important issue.

The challenge for scientists and clinicians is to develop EMAI and JITAIs with the support of AI techniques. Designing automatic delivery of JITAIs, formulated by the app or by a doctor/therapist based on incoming data, will require an innovative approach in using existing scientific and therapeutic standards as well as new research into the dynamics of ongoing interventions. Nahum Shani et al. [67] emphasize the need for further efforts to develop dynamic theories of health behavior in the context of JITAIs. They claim that, despite the increasing use and appeal of JITAI, a major gap exists between the growing technological capabilities for delivering JITAIs and research on the development and evaluation of these interventions. Thus, there is a need for researchers and clinicians to be involved in the creation of JITAIs based on empirical evidence, theory, and accepted treatment guidelines. The authors point out that building an empirical basis on which to construct such dynamic models requires studies and methods that capitalize on the rich, fine-grained, temporal data that can now be collected using ubiquitous mobile and wireless technology. The basis for creating new dynamic behavioral models in medicine and their effective implementation are to be found in new study designs (e.g. MRT, micro-randomized trials) and data analytic methods (e.g. continuous updating of the JITAI decision rules depending on the effects of previous interventions). Additionally, Nahum Shani emphasize the need to train researchers in innovative approaches to creating study designs and analytic methods suitable for mobile health data.

In the context of EMAI and JITAIs, important factors in the introduction of innovative, more effective diagnostic and therapeutic methods is the chronic nature and variability of tinnitus and its susceptibility to various factors. Suitable methods will be needed to increase the effectiveness of therapeutic devices and hearing rehabilitation using hearing aids, cochlear implants, and other portable therapeutic devices. More effective methods will need to balance many factors, e.g. whether an individual suffers from hearing loss, tinnitus, or sound hypersensitivity.

In the area of tinnitus rehabilitation, previous findings suggest that mobile apps offer great potential for self-help therapeutic methods. They can be stand-alone methods or support methods offered by specialists. The introduction of clinically verified therapeutic methods based on mobile apps into the public health system will involve several stages. Therapeutic programs will need to be optimized in terms of intuitiveness and attractiveness. This is important for making independently run therapies effective and maintaining a high level of motivation. The next important step is to verify the efficacy of the apps in large randomized control clinical trials. Therapies based on mobile apps will also require linguistic and cultural adaptation in order to disseminate them around the world and perform clinical re-verification. The final challenge is to create educational programs for specialists – training modules – for individual mobile apps, setting out their therapeutic possibilities and areas of application.

Conclusions

1. Based on smartphone-based apps with ecological momentary assessments (EMAs), the possibility arises of using them and various wearable diagnostic devices to better understand the variability of tinnitus and its causes.
2. Combining mobile apps with mobile crowd sensing, central databases collecting anonymized user data, and AI support creates a valuable source for scientific research.
3. Clinically verified methods delivered by mobile apps could become part of a specialist-endorsed therapeutic process that supports easy, low-cost, and wide range therapy for dealing with tinnitus.
4. Multifunctional smart devices – such as hearing aids, cochlear implants, and hearables – and managed by mobile apps may become equally important in tinnitus therapy.
5. In the future, the development of mobile technologies and AI techniques will contribute to the creation of smart therapy platforms for tinnitus.

References

1. De Ridder D, Schlee W, Vanneste S, Londero A, Weisz N, Kleinjung T, et al. Tinnitus and tinnitus disorder: theoretical and operational definitions (an international multidisciplinary proposal). Prog Brain Res, 2021; 260: 1–25. https://doi.org/10.1016/bs.pbr.2020.12.002
2. Cima RRF, Mazurek B, Haider H, Kikidis D, Lapira A, Norena A, et al. A Multidisciplinary European Guideline for Tinnitus: diagnostics, assessment, and treatment. HNO, 2019; 67: 10–42. https://doi.org/10.1007/s00106-019-0633-7
3. Baguley D, McFerran D, Hall D. Tinnitus. Lancet, 2013; 382: 1600–7. https://doi.org/10.1016/S0140-6736(13)60142-7
4. Makar SK. Etiology and pathophysiology of tinnitus: a systematic review. Int Tinnitus J, 2021; 25(1): 76–86. https://doi.org/10.5935/0946-5448.20210015
5. Hoffman HJ, Reed GW. Epidemiology of tinnitus. In: Snow JB, editor. Tinnitus: Theory and Management. London: B.C. Decker Inc., 2004; pp. 16–41.
6. Henry JA, Dennis KC, Schechter MA. General review of tinnitus: prevalence, mechanisms, effects, and management. J Speech Lang Hear Res, 2005; 48(5): 1204–35. https://doi.org/10.1044/1092-4388(2005/084)
7. Shargorodsky J, Curhan GC, Farwell WR. Prevalence and characteristics of tinnitus among US adults. Am J Med, 2010; 123(8): 711–8. https://doi.org/10.1016/j.amjmed.2010.02.015
8. Skarżyński H, Rogowski M, Fabijańska A, Bartnik G, Raj-Koziak D. The epidemiology of hearing disorders in Poland. In: Jahnke K, Fischer M, editors. 4th European Congress of Oto-Rhino-Laryngology Head and Neck Surgery, May 13–18, 2000. Berlin: Monduzzi Editore; pp. 159–63.
9. Nondahl DM, Cruickshanks KJ Dalton DS, Klein BE, Klein R, Schubert CR, et al. The impact of tinnitus on quality of life in older adults. J Am Acad Audiol, 2001; 18(3): 257–66. https://doi.org/10.3766/jaaa.18.3.7
10. Bhatt JM, Bhattacharyya N, Lin HW. Relationships between tinnitus and the prevalence of anxiety and depression. Laryngoscope, 2017; 127: 466–9. https://doi.org/10.1002/lary.26107
11. Koning HM. Sleep disturbances associated with tinnitus: reduce the maximal intensity of tinnitus. Int Tinnitus J, 2019; 23: 64–8. https://doi.org/10.5935/0946-5448.20190012
12. Hackenberg B, Döge J, O'Brien K, Bohnert A, Lackner KJ, Beutel ME, et al. Tinnitus and its relation to depression, anxiety, and stress: a population-based cohort study. J Clin Med, 2023; 12: 1169. https://doi.org/10.3390/jcm12031169
13. Probst T, Pryss R, Langguth B, Schlee W. Emotion dynamics and tinnitus: daily life data from the "TrackYourTinnitus application". Sci Rep, 2016; 6: 31166. https://doi.org/10.1038/srep31166
14. Probst T, Pryss R, Langguth B, Rauschecker JP, Schobel J, Reichert M, et al. Does tinnitus depend on time-of-day? An Ecological Momentary Assessment Study with the TrackYourTinnitus application. Front Aging Neurosci, 2017; 9: 253. https://doi.org/10.3389/fnagi.2017.00253
15. Pryss R, Probst T, Schlee W, Schobel J, Langguth B, Neff P, et al. Prospective crowdsensing versus retrospective ratings of tinnitus variability and tinnitus – stress associations based on the TrackYourTinnitus mobile platform. IJDSA, 2019; 8: 327–38. https://doi.org/10.1007/s41060-018-0111-4
16. Tunkel DE, Bauer CA, Sun GH, Rosenfeld RM, Chandrasekhar SS, Cunningham ER et al. Clinical practice guideline: tinnitus executive summary. Otolaryngol Head Neck Surg, 2014; 151: 533–41. https://doi.org/10.1177/0194599814547475
17. Lewis S, Chowdhury E, Stockdale D, Kennedy V. Assessment and management of tinnitus: summary of NICE guidance. BMJ, 2020; 368: m976. https://doi.org/10.1136/bmj.m976
18. Mazurek B, Schulze H, Schlee W, Dobel C. Tinnitus at the junction of traditional medicine and modern technology. Nutrients, 2023; 15(8): 1898. https://doi.org/10.3390/nu15081898
19. Lecomte T, Potvin S, Corbière M, Guay S, Samson C, Cloutier B, et al. Mobile apps for mental health issues: meta-review of meta-analyses. JMIR mHealth and uHealth 2020; 8: e17458. https://doi.org/10.2196/17458
20. Hosseini A, Eshraghi MA, Taami T, Sadeghsalehi H, Hoseinzadeh Z, Ghaderzadeh M. A mobile application based on efficient lightweight CNN model for classification of B-ALL cancer from non-cancerous cells: a design and implementation study. IMU, 2023; 39. https://doi.org/10.1016/j.imu.2023.101244
21. Gheisari M, Ghaderzadeh M, Li H, Taami T, Fernández-Campusano C, Sadeghsalehi H, Afzaal Abbasi A. Mobile apps for COVID-19 detection and diagnosis for future pandemic control: multidimensional systematic review. JMIR mHealth uHealth, 2024; 12: e44406. https://doi.org/10.2196/44406
22. Mehdi M, Riha C, Neff P, Dode A, Pryss R, Schlee W, et al. Smartphone apps in the context of tinnitus: systematic review. Sensors, 2020; 20(6): 1725. https://doi.org/10.3390/s20061725
23. Mehdi M, Stach M, Riha C, Neff P, Dode A, Pryss R, et al. Smartphone and mobile health apps for tinnitus: systematic identification, analysis, and assessment. JMIR mHealth uHealth, 2020; 8(8): e21767. https://doi.org/10.2196/21767
24. Mehdi M, Dode A, Pryss R, Schlee W, Reichert M, Hauck FJ, et al. Contemporary review of smartphone apps for tinnitus management and treatment. Brain Sci, 2020; 17; 10(11): 867. https://doi.org/10.3390/brainsci10110867
25. Nagaraj MK, Prabhu P. Internet/smartphone-based applications for the treatment of tinnitus: a systematic review. Eur Arch Otorhinolaryngol, 2020, 277(3): 649–57. https://doi.org/10.1007/s00405-019-05743-8
26. Deshpande AK, Shimunova T. A comprehensive evaluation of tinnitus apps. Am J Audiol, 2019; 28(3): 605–16. https://doi.org/10.1044/2019_AJA-18-0135
27. Sereda M, Smith S, Newton K, Stockdale D. Mobile apps for management of tinnitus: users' survey, quality assessment, and content analysis. JMIR mHealth uHealth, 2019; 7(1). https://doi.org/10.2196/10353
28. Kutyba J, Jędrzejczak WW, Gos E, Raj-Koziak D, Skarżyński PH. [Mobile applications useful in tinnitus sound therapy: review of tools available in the Polish language]. Med Og Nauk Zdr, 2021; 27(2): 151–6 [in Polish]. https://doi.org/10.26444/monz/136030
29. Chamoso P, De La Prieta F, Eibenstein A, Santos-Santos D, Tizio A, Vittorini P. A device supporting the self-management of tinnitus. In: Rojas I, Ortuño F, editors. Proceedings of the 5th International Conference on Bioinformatics and Biomedical Engineering, IWBBIO 2017, Granada, Spain, April 2017. Heidelberg: Springer; 2017, pp. 399–410. https://doi.org/10.1007/978-3-319-56154-7_36
30. Vittorini P, Chamoso P, De la Prieta F. A device and an app for the diagnosis and self-management of tinnitus. J Integrative Bioinf, 2022; 19(3). https://doi.org/10.1515/jib-2022-0004
31. Handzel O, Franck K. Smartphone-based hearing evaluation. Oper Tech Otolaryngol, 2021; 32: 87–91. http://doi.org/10.1016/j.otot.2021.05.004

32. Schlee W, Kraft R, Schobel J, Langguth B, Probst T, Neff P, et al. Momentary assessment of tinnitus: how smart mobile applications advance our understanding of tinnitus. In: Baumeister H, Montag C, editors. Digital Phenotyping and Mobile Sensing: New Developments in Psychoinformatics. Edinburgh: Springer Cham; 2019, pp. 209–20.
33. Schleicher M, Unnikrishnan V, Neff P, Simoes J, Probst T, Pryss R, et al. Understanding adherence to the recording of ecological momentary assessments in the example of tinnitus monitoring. Sci Rep, 2020; 10: 22459. https://doi.org/10.1038/s41598-020-79527-0
34. Henry JA, Galvez G, Turbin MB, Thielman EJ, McMillan GP, Istvan JA. Pilot study to evaluate ecological momentary assessment of tinnitus. Ear Hear, 2012; 33(2): 179–290. https://doi.org/10.1097/AUD.0b013e31822f6740.
35. Wilson MB, Kallogjeri D, Joplin CN, Gorman MD, Krings JG, Lenze EJ, et al. Ecological momentary assessment of tinnitus using smartphone technology: a pilot study. Otolaryngol Head Neck Surg, 2015; 152(5): 897–903. https://doi.org/10.1177/0194599815569692.
36. Schlee W, Pryss RC, Probst T, Schobel J, Bachmeier A, Reichert M, Langguth B. Measuring the moment-to-moment variability of tinnitus: the TrackYourTinnitus smart phone app. Front Aging Neurosci, 2016; 8: 294. https://doi.org/10.3389/fnagi.2016.00294
37. Kraft R, Stach M, Reichert M, Schlee W, Probst T, Langguth B, et al. Comprehensive insights into the TrackYourTinnitus database. In: 17th International Conference on Mobile Systems and Pervasive Computing (MobiSPC), Leuven, Belgium, August 2020. Procedia Comput Sci, 2020; 175, 28–35.
38. Pryss R, Reichert M, Langguth B, Schlee W. Mobile crowd sensing services for tinnitus assessment, therapy and research. In: 2015 IEEE International Conference on Mobile Services (MS), June 27 – July 2, 2015, New York, USA. https://doi.org/10.1109/MobServ.2015.55
39. Dode A, Mehdi M, Pryss R, Schlee W, Probst T, Reichert M, et al. Using a Visual Analog Scale (VAS) to measure tinnitus-related distress and loudness: investigating correlations using the Mini-TQ results of participants from the TrackYourTinnitus platform. Prog Brain Res, 2021; 263: 171–90. https://doi.org/10.1016/bs.pbr.2020.08.008
40. Prys R, Schlee W, Langguth B, Reichert M. Mobile crowdsensing services for tinnitus assessment and patient feedback. In: IEEE International Conference on AI & Mobile Services (AIMS), June 25–30, 2017, Honolulu, USA. https://doi.org/:10.1109/AIMS.2017.12
41. Kraft R, Schlee W, Stach M, Reichert M, Langguth B, Baumeister H, et al. Combining mobile crowdsensing and ecological momentary assessments in the healthcare domain. Front Neurosci, 2020; 14: 164. https://doi.org/10.3389/fnins.2020.00164
42. Breitmayer M, Stach M, Kraft R, Allgaier J, Reichert M, Schlee W, et al. Predicting the presence of tinnitus using ecological momentary assessments. Sci Rep, 2023; 13: 8989. https://doi.org/10.1038/s41598-023-36172-7
43. Allgaier J, Schlee W, Langguth B, Probst T, Pryss R. Predicting the gender of individuals with tinnitus based on daily life data of the TrackYourTinnitus mHealth platform. Sci Rep, 2021; 11: 18375. https://doi.org/10.1038/s41598-021-96731-8
44. Pryss R, Schlee W, Hoppenstedt B, Reichert M, Spiliopoulou M, Langguth B, et al. Applying machine learning to daily-life data from the TrackYourTinnitus mobile health crowdsensing platform to predict the mobile operating system used with high accuracy: longitudinal observational study. J Med Internet Res, 2020; 22(6): e15547. https://doi.org/10.2196/15547
45. Hauptmann C, Wegener A, Poppe H, Williams M, Popelka G, Tass PA. Validation of a mobile device for acoustic coordinated reset neuromodulation tinnitus therapy. J Am Acad Audiol, 2016; 27: 720–31. https://doi.org/10.3766/jaaa.15082
46. Kim SY, Chang MY, Hong M, Yoo S-G, Oh D, Park MK. Tinnitus therapy using tailor-made notched music delivered via a smartphone application and ginko combined treatment: a pilot study. Auris Nasus Larynx, 2017; 44, 528–33. http://dx.doi.org/10.1016/j.anl.2016.11.003
47. Tyler RS, Owen RL, Bridges J, Gander PE, Perreau A, Mancini PC. Tinnitus suppression in cochlear implant patients using a sound therapy app. Am J Audiol, 2018; 27: 316–23. https://doi.org/10.1044/2018_AJA-17-0105
48. Sabarish A, Kruthika S. Efficacy of sound therapy using android based application in individual with tinnitus. In: Seva Sadan International Multidisciplinary Conference on "Use of Digital Technology in Business, Financial Services and Education Systems: Challenges & Opportunities", February 2019, Ulashnagar, India. https://doi.org/10.13140/RG.2.2.35114.47047
49. Kutyba J, Gos E, Jędrzejczak WW, Raj-Koziak D, Karpiesz L, Niedziałek I, et al. Effectiveness of tinnitus therapy using a mobile application. Eur Arch Otorhinolaryngol, 2022; 279(3): 1257–67. https://doi.org/10.1007/s00405-021-06767-9
50. Abouzari M, Goshtasbi K, Sarna B, Ghavami Y, Parker EM, Khosravi P, et al. Adapting personal therapies using a mobile application for tinnitus rehabilitation: a preliminary study. Ann Otol Rhinol Laryngol, 2021; 130(6): 571–7. https://doi.org/10.1177/0003489420962818
51. Tang D, Wang H, Ye Z, Gu D, Ye L, Sun S, Li H. The Fudan Tinnitus Relieving System (FTRS): the initial results of a smartphone application for tinnitus management and treatment. Internet Interv, 2022; 29: 100564. https://doi.org/10.1016/j.invent.2022.100564
52. Tang D, Wang H, Gu D, Ye L, Sun S, Li H. The Fudan Tinnitus Relieving System application for tinnitus management. BMC Med Inform Decision Mak, 2023; 23: 76. https://doi.org/10.1186/s12911-023-02164-w
53. Engelke M, Simões J, Vogel C, Schoisswohl S, Schecklmann M, Wölflick S, et al. Pilot study of a smartphone-based tinnitus therapy using structured counseling and sound therapy: a multiple-baseline design with ecological momentary assessment. PLoS Digit Health, 2023; 2(1): e0000183. https://doi.org/10.1371/journal.pdig.0000183
54. Suh M-W, Park MK, Kim Y, Kim YH. The treatment outcome of smart device-based Tinnitus Retraining Therapy: prospective cohort study. JMIR mHealth uHealth, 2023; 11: e38986. https://doi.org/10.2196/38986
55. Walter U, Pennig S, Kottmann T, Bleckmann L, Röschmann-Doose K, Schlee W. Randomized controlled trial of a smartphone-based cognitive behavioral therapy for chronic tinnitus. PLOS Digit Health, 2023; 2(9): e0000337. https://doi.org/10.1371/journal.pdig.0000337
56. Henry JA, Thielman E, Zaugg T, Kaelin Ch, Choma C, Chang B, et al. Development and field testing of a smartphone "app" for tinnitus management. Int J Audiol, 2017; 56: 784–92. https://doi.org/10.1080/14992027.2017.1338762

57. Schlee W, Neff P, Simoes J, Langguth B, Schoisswohl S, Steinberger H, et al. Smartphone-guided educational counseling and self-help for chronic tinnitus. J Clin Med, 2022; 11: 1825. http://doi.org/10.3390/jcm11071825
58. Oron Y, Ben David BM, Doron G. Brief cognitive-behavioral training for tinnitus relief using a mobile application: a pilot open trial. Health Informatics J, 2022; 28: 1. https://doi.org/10.1177/14604582221083483
59. Schickler M, Pryss R, Reichert M, Schobel J, Langguth B, Schlee W. Using mobile serious games in the context of chronic disorders: a mobile game concept for the treatment of tinnitus. In: IEEE 29th International Symposium on Computer-Based Medical Systems (CBMS), Dublin, Ireland, June 20–24, 2016; p. 343–8. https://doi.org/10.1109/CBMS.2016.9
60. Demoen S, Jacquemin L, Timmermans A, Van Rompaey V, Vanderveken O, Vermeersch H, et al. Cost-effectiveness of a smartphone application for tinnitus treatment (the CATT trial): a study protocol of a randomised controlled trial. Trials, 2022; 23: 435. https://doi.org/10.1186/s13063-022-06378-7
61. Bardy F, Jacquemin L, Wong CL, Maslin MRD, Purdy SC, Thai-Van H. Delivery of internet-based cognitive behavioral therapy combined with human-delivered telepsychology in tinnitus sufferers through a chatbot-based mobile app. Front Audiol Otol, 2024; 1: 1302215. https://doi: 10.3389/fauot.2023.1302215
62. Searchfield GD, Sanders PJ, Doborjeh Z, Doborjeh M, Boldu R, Sun K, et al. A state-of-art review of digital technologies for the next generation of tinnitus therapeutics. Front Digit Health, 2021; 3: 724370. https://doi.org/10.3389/fdgth.2021.724370
63. Milne-Ives M, Selby E, Inkster B, Lam C, Meinert E. Artificial intelligence and machine learning in mobile apps for mental health: a scoping review. PLOS Digit Health, 2022; 1(8): e0000079. https://doi.org/10.1371/journal.pdig.0000079
64. Menictas M, Rabbi M, Klasnja P, Murphy S. Artificial intelligence decision-making in mobile health. Biochem (Lond), 2019; 41(5): 20–4. https://doi.org/10.1042/bio04105020
65. Stach M, Vogel C, Gablonski TC, Andreas S, Probst T, Reichert M, et al. Technical challenges of a mobile application supporting intersession processes in psychotherapy. Procedia Comput Sci, 2020; 175: 261–68. https://doi.org/10.1016/j.procs.2020.07.038
66. Balaskas A, Schueller SM, Cox AL, Doherty G. Ecological momentary interventions for mental health: a scoping review. PLoS One, 2021; 16(3): e0248152. https://doi.org/10.1371/journal.pone.0248152
67. Nahum-Shani I, Smith SN, Spring BJ, Collins LM, Witkiewitz K, Tewari A, et al. Just-in-time adaptive intervention (JITAIs) in mobile health: key components and design principles for ongoing health behavior support. Ann Behav Med, 2018; 52(6): 446–62. https://doi.org/10.1007/s12160-016-9830-8
68. Manta O, Sarafidis M, Schlee W, Mazurek B, Matsopoulos GK, Koutsouris DD. Development of machine-learning models for tinnitus-related distress classification using wavelet-transformed auditory evoked potential signals and clinical data. J Clin Med, 2023; 12: 3843. https://doi.org/10.3390/jcm12113843
69. Doborjeh M, Liu X, Doborjeh Z, Shen Y, Shen Y, Searchfield G, et al. Prediction of tinnitus treatment outcomes based on EEG sensors and TFI score using deep learning. Sensors, 2023; 23: 902. https://doi.org/10.3390/s23020902
70. Moulya S, Pragathi T. Mental health assist and diagnosis conversational interface using logistic regression model for emotion and sentiment analysis. J Phys Conf Ser, 2022; 2161(1): 012039. https://doi.org/10.1088/1742-6596/2161/1/012039
71. Karkosz S, Szymański R, Sanna K, Michałowski J. Effectiveness of a web-based and mobile therapy chatbot on anxiety and depressive symptoms in subclinical young adults: randomized controlled trial. JMIR, 2024; 8: e47960 [preprints, 6.04.2023]. https://preprints.jmir.org/preprint/47960
72. Klos MC, Escoredo M, Joerin A, Lemos VN, Rauws M, Bunge EL. Artificial Intelligence-based chatbot for anxiety and depression in university students: pilot randomized controlled trial. JMRI Form Res, 2024; 8: e47960. https://doi.org/10.2196/47960
73. Pryss R, Kraft R, Baumeister H, Winkler J, Probst T, et al. Using chatbots to support medical and psychological treatment procedures: challenges, opportunities, technologies, reference architecture. In: Baumeister H, Montag C, editors. Digital Phenotyping and Mobile Sensing: New developments in psychoinformatics. Edinburgh: Springer Cham; 2019, pp. 249–60.
74. Gutu SM, Cosmoiu A, Cojocaru D, Turturescu T, Popoviciu CM, Giosan C. Bot to the rescue? Effects of a fully automated conversational agent on anxiety and depression: a randomized controlled trial. Ann Depress Anxiety, 2021; 8(1): 1107. https://doi.org/10.26420/anndepressanxiety.2021.1107
75. Fulmer R, Joerin A, Gentile B, Lakerink L, Rauws M. Using psychological artificial intelligence (Tess) to relieve symptoms of depression and anxiety: randomized controlled trial. JMIR Ment Health, 2018; 13; 5(4): e64. https://doi.org/10.2196/mental.9782
76. Kraft R, Birk F, Reichert M, Deshpande A, Schlee W, Langguth B, et al. Design and implementation of scalable crowdsensing platform for geospatial data of tinnitus patients. In: IEEE 32nd International Symposium on Computer-Based Medical Systems (CBMS), June 5–7, 2019, Cordoba, Spain. https://doi.org/10.1109/CBMS.2019.00068
77. Xia Y, Hu J, Zhao S, Tao L, Li Z, Yue T, et al. Build-in sensors and analysis algorithms aided smartphone-based sensors for point-of-care tests. Biosensors Bioelectronics X, 2022; 11: 100195. https://doi.org/10.1016/j.biosx.2022.100195
78. Mehdi M, Schwager D, Pryss R, Schlee W, Reichert M, Hauck FJ. Towards automated smart mobile crowdsensing for tinnitus research. In: IEEE 32nd International Symposium on Computer-Based Medical Systems (CBMS), June 5–7, 2019, Cordoba, Spain. https://doi.org/10.1109/CBMS.2019.00026
79. Kraft R, Birk F, Reichert M, Deshpande A, Schlee, W, Langguth B, et al. Efficient processing of geospatial mHealth data using a scalable crowdsensing platform. Sensors, 2020; 20: 3456. https://doi.org/10.3390/s20123456
80. Kalle S, Schlee W, Pryss R, Probst T, Reichert M, Langguth B, et al. Review of smart services for tinnitus self-help, diagnostics and treatments. Front Neurosci, 2018; 12: 541. https://doi.org/10.3389/fnins.2018.00541

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IMPACT OF ADENOTONSILLECTOMY ON ASTHMA CONTROL IN PEDIATRIC PATIENTS: A SYSTEMATIC REVIEW

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Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

Abstract

Introduction: This systematic review investigates the influence of adenotonsillectomy (AT) on asthma control in pediatric patients.

Material and methods: A literature review from 2000 to 2023 based on the databases PubMed, the Cochrane Library, and Web of Science. The analysis is distilled down to four studies that revealed positive outcomes in asthma control as gauged by the Asthma Control Test (ACT), the Childhood Asthma Control Test (C-ACT), clinical outcomes, and asthma-related chitinase levels.

Results: The four studies consistently demonstrated improved asthma control postoperatively in terms of improved ACT scores, reductions in acute asthma exacerbations, emergency room visits, hospitalisations, and medication usage. Notably, the correlation between improved asthma control and decreased chitinase activity suggests that AT has an impact on molecular markers associated with asthma.

Conclusions: The findings underline the potential benefits of AT in pediatric asthma management. However, the limitations of this study include a small number of studies and potential biases related to asthma's natural course and seasonal variations. While the review provides evidence for the positive impact of AT on asthma control, further research with longer follow-up periods, case-matched controls, and consideration of seasonal factors is recommended.

Keywords: chitinase • asthma control • ACT • pediatric astma • adenotonsillectomy • C-ACT

WPŁYW ADENOTONSILLEKTOMII NA KONTROLĘ ASTMY U PACJENTÓW PEDIATRYCZNYCH – PRZEGLĄD SYSTEMATYCZNY

Streszczenie

Wstęp: Celem tej pracy jest dokonanie przeglądu literatury dotyczącej wpływu zabiegu adenotonsillektomii na jakość kontroli astmy u pacjentów pediatrycznych.

Materiał i metody: Przeprowadzono przegląd literatury naukowej z wykorzystaniem baz PubMed, Cochrane Library i Web of Science, uwzględniając publikacje z lat 2000–2023. Analiza objęła ostatecznie cztery publikacje ukazujące poprawę jakości kontroli astmy w takich miarach jak Asthma Control Test (ACT) i Childhood Asthma Control Test (C-ACT), a także zawierające rezultaty leczenia oraz poziomy chitynazy związanej z astmą.

Wyniki: Cztery zaprezentowane badania konsekwentnie wykazały pooperacyjną poprawę jakości kontroli astmy, manifestującą się jako poprawa wyników testu ACT lub C-ACT, ograniczenie liczby zaostrzeń astmy, wizyt w oddziałach ratunkowych i hospitalizacji oraz zmniejszenie przyjmowania leków. Warto zauważyć, że związek pomiędzy poprawą kontroli astmy a obniżeniem aktywności chitynazy sugeruje wpływ adenotonsillektomii na markery molekularne związane z astmą.

Wnioski: Wyniki świadczą o potencjalnych korzyściach z zastosowania adenotonsillektomii w leczeniu astmy u dzieci, jednak należy wziąć pod uwagę jego pewne ograniczenia, takie jak niewielka liczba uwzględnionych badań oraz potencjalne błędy związane z naturalnym przebiegiem astmy oraz sezonowymi zmianami. Mimo że przegląd dostarcza dowodów na pozytywny wpływ adenotonsillektomii na jakość kontroli astmy, zaleca się dalsze badania z uwzględnieniem nie tylko dłuższego czasu obserwacji i grupy kontrolnej dopasowanej do przypadków, lecz także czynników sezonowych.

Słowa kluczowe: chitynaza • kontrola astmy • ACT • astma dziecięca • adenotonsillektomia • C-ACT

Key for abbreviations	
A	adenoidectomy
AAE	acute asthma exacerbation
ACT	Asthma Control Test
ARER	emergency room visits related to asthma
ARH	asthma-related hospitalisations
ASA	acute status asthmaticus
AT	adenotonsillectomy
C-ACT	Childhood Asthma Control Test

Introduction

Asthma is one of the most common respiratory diseases in Poland. According to a BUPAS study of children aged 7–13 years, 3.5% of them who lived in rural areas and 4.1% of them who lived in urban areas suffered from asthma symptoms [1]. The total value of reimbursement for provided services with a diagnosis of asthma (J45, J46 according to ICD-10) amounted to PLN 257.1 million in 2019 [2,3]. Asthma is a chronic respiratory disease characterised by variable airflow obstruction, bronchial hyperresponsiveness, and airway inflammation.

The most important factor contributing to asthma development is considered to be the presence of allergic rhinitis, especially among individuals with additional confirmed bronchial hyperresponsiveness [4]. Epidemiological studies have also shown several demographic, developmental, and environmental factors that appear to influence the onset of the disease. The most crucial are low birth weight, parental smoking, use of antibiotics, and paracetamol. Additionally, individuals living in urban areas, which are more exposed to breathing polluted air, are more prone to the condition.

The most effective and basic treatment for bronchial asthma is therapy with inhaled glucocorticosteroids. This treatment, consisting of small doses taken regularly, is sufficient for the majority of patients. Additionally, in pharmacological therapy, bronchodilator drugs are also used. These are most commonly long-acting and short-acting beta2-agonists. These drugs are used as needed and should not be the base of pharmacological therapy. According to current recommendations, the preferred method for the emergency treatment of a sudden breathlessness attack is the use of small doses of inhaled glucocorticosteroid with a long-acting beta2-agonist [2,5].

Adenoidectomy (A) alone or combined with tonsillectomy as an adenotonsillectomy (AT) is one of the most common surgeries performed in Poland. Based on statistics from 2017, approximately 43,192 of these surgeries are performed annually [6]. Adenoidectomy involves surgical removal of the adenoid, and adenotonsillectomy is the removal of the adenoid and both tonsils. Two primary categories of indications for these procedures are recurrent upper respiratory tract infections and sleep-related breathing disorders [7].

While observational studies suggest a potential improvement in asthma management after undergoing AT, the existing literature lacks a comprehensive analysis and synthesis. The objective of this study was to perform a systematic review of all relevant studies investigating the impact of AT on asthma control in pediatric patients. By synthesising findings, this review aims to help identify those children who are most likely to benefit from AT, supporting the rationale of using AT as an intervention for asthma in pediatric patients. Additionally, considering the dynamic nature of medical research and the continuous evolution of clinical practice, updating our understanding of the role of AT in asthma management is crucial. Thus, this review seeks to refine knowledge and inform evidence-based decisionmaking in pediatric asthma care.

Material and methods

We conducted a comprehensive literature review using the databases PubMed, the Cochrane Library, and Web of Science. The search strategy involved the use of keywords "adenoid and asthma", "adenoidectomy and asthma", "adenotonsillectomy and asthma", and "tonsillectomy and asthma". We limited the time frame to the years 2000–2023 and restricted the search to English-language articles. Our inclusion criteria were pediatric patients aged 18 years or younger, diagnosed with asthma, and undergoing adenotonsillectomy as a treatment for recurrent infections or obstructive sleep apnea. Based on the keywords, a total of 507 records were obtained. Of these, 194 were excluded before screening as duplicates, and 300 were excluded due to not meeting the inclusion criteria. We assessed 13 articles for full-text access, and after applying all exclusion criteria, 4 articles were left for qualitative synthesis. The results and specific exclusion criteria are summarised in the PRISMA chart of **Figure 1** [8].

To assess and minimise bias, we conducted a thorough evaluation of the study design, methodology, and potential sources of bias of each study involved in the review. **Table 1** compares key characteristics of the four included studies, setting out number of patients, control group characteristics, results analysed, and study character.

Results

Asthma clinical outcomes

All four studies included in the review took into consideration various aspects of asthma clinical outcomes. The clinical outcomes differed between the studies.

The biggest study group was that of the Bhattacharjee et al. study [9]. Using the 2003–10 MarketScan database, they analysed 13,506 children with asthma who underwent AT matched with 27,012 asthmatic children not undergoing the AT procedure. Asthmatic children were identified from the MarketScan database using the ICD-9 code for asthma. From this cohort, asthmatic children who had undergone AT were identified using current procedural terminology codes for AT. Control group patients were chosen based on meeting the criteria for asthma but did not have a history of any current procedural terminology codes for AT, adenoidectomy, and tonsillectomy. Patients

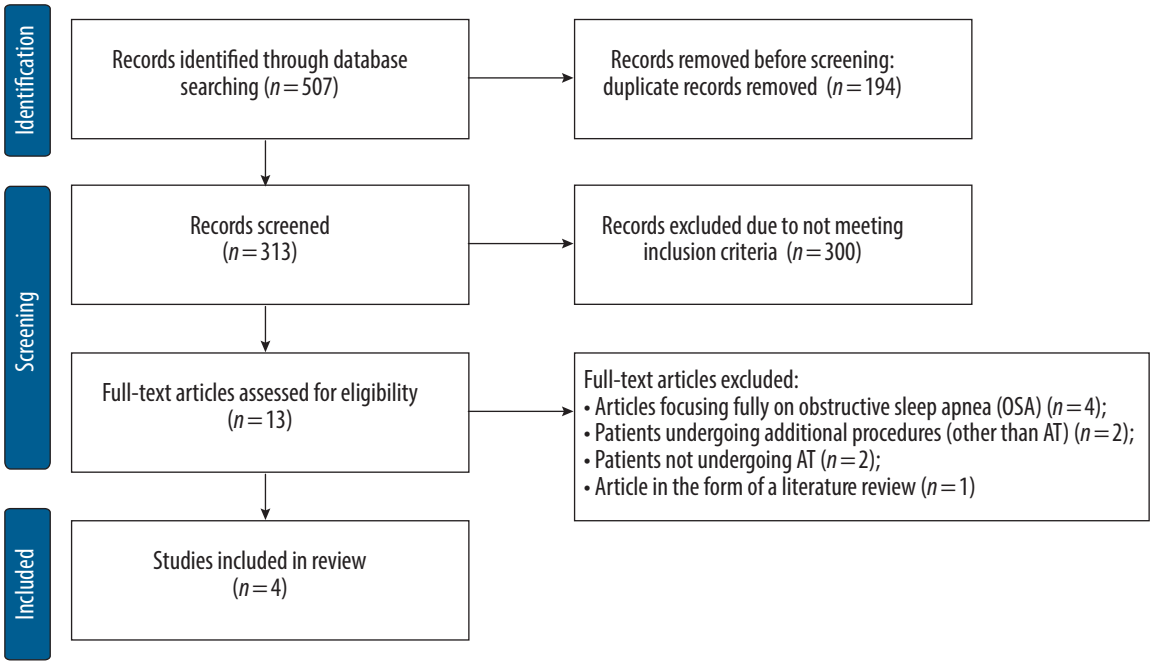

Figure 1. PRISMA 2020 flow diagram

Table 1. Comparison of the four key studies

Study	Bhattacharjee et al.	Goldstein et al.	Levin et al.	Busino et al.
Number of patients	Intervention: 13,506 Control: 27,012	Intervention: 80 Control: 62	Intervention: 64 Control: 66	Intervention: 93 Control: 372
Control group characteristics	Asthmatic children not undergoing AT procedure	Asthmatic children not undergoing AT procedure	Children without asthma diagnosis undergoing AT procedure	Children without asthma diagnosis undergoing AT procedure
Results analysed	Frequency of acute asthma exacerbation, acute status asthmaticus, emergency room visits related to asthma, asthma-related hospitalisations, changes in prescriptions for asthma medications	C-ACT score, count of asthma exacerbations, number of courses of systemic steroids, emergency room visits, and hospitalisations over 6 months	C-ACT score, frequency of emergency room visits/urgent care visits for asthma, oral corticosteroid courses, hospitalisation for asthma, missed days due to asthma, chitinase activity	ACT score, frequency of hospital visits, systemic steroid use, asthma medication use
Study character	Longitudinal database analysis	Prospective, controlled study	Longitudinal observational study	Retrospective chart review

from the control group were matched with patients undergoing AT by age, sex, home location, and geographical state of residence. MarketScan is a large database of over 180 million patients including a large cohort of children that collects payment information, capturing reimbursements from health insurance plans and payments accrued by patients in the USA [9].

The primary outcomes focused on the presence of a diagnostic code indicating acute asthma exacerbation (AAE) or acute status asthmaticus (ASA). Secondary outcomes involved temporal changes in prescriptions for asthma medications, the frequency of emergency room visits related to asthma (ARERs), and asthma-related hospitalisations (ARHs). The frequency of outcomes for patients with asthma who underwent adenotonsillectomy (AT+) was assessed for the 1-year period preceding the AT date and compared to the 1-year period following the AT date. For the control group AT– patients, the frequency of outcomes was examined over a corresponding 2-year duration. The occurrence of acute asthma exacerbation (AAE) and acute status asthmaticus (ASA) episodes significantly decreased in children who underwent adenotonsillectomy (AT+) compared to those who did not (AT–) between the first year and the second year of follow-up. Specifically, the frequency of AAE decreased from 2,243 before AT to 1,566 after AT in AT+ children compared to a decrease from 3,403 in the first year to 3,336 in the second year in

the AT– group, resulting in a relative risk reduction of 30% versus 2% (p<0.0001).

The occurrence of acute status asthmaticus (ASA) declined in AT+ patients, decreasing from 562 incidents before AT to 349 after AT. In comparison, in AT– patients, the frequency went from 837 in the first year to 778 in the second year. This resulted in a relative risk reduction of 38% versus 7% (p<0.0001).

The reductions in both AAE and ASA were present across all age groups of AT+ patients. Comparing prescription refills of AT+ patients to AT– patients, the former experienced significant decreases in most classes of asthma prescriptions during the 1-year period following the procedure. Analysis showed a 16.7% reduction in prescription refills for bronchodilators, a 21.5% reduction for inhaled corticosteroids, and a 13.4% reduction for leukotriene receptor antagonists. In terms of the number of children per 1,000 who obtained various asthma prescriptions before AT, more AT+ children required prescriptions for bronchodilators, inhaled corticosteroids, and leukotriene receptor antagonists compared to the AT– control group. After the AT, the number of AT+ children requiring these therapies decreased to levels comparable to those of AT– children. The number of prescription refills of systemic corticosteroids, potentially indicative of an asthma exacerbation, showed a significant decrease in the AT+ group compared to the corresponding second year of follow-up in AT– patients (23.7% versus 7.3% reduction; $p = 0.003$). The occurrences of asthma-related emergency room visits (ARERs) and asthma-related hospitalisations (ARHs) were markedly decreased in the AT+ group after AT compared to the AT– group (25.6% versus 0.0% reduction; $p < 0.0001$; and 35.8% versus 12.2% reduction; $p = 0.0025$) [9].

The study by Levin et al. [10] analysed 66 patients diagnosed with asthma, alongside a control group comprising 64 patients without asthma (both undergoing AT). Some 75% of the study participants underwent surgery primarily due to tonsillar hypertrophy, including symptoms of sleep-disordered breathing, whereas 23% of participants underwent surgery primarily due to recurrent tonsillitis/infection. Follow-up was achieved in 81% of all enrolled patients, with the mean time to follow-up after surgery being 7 months (range 5–12; SD = 1.5); the rate was not statistically different between groups. The analysis focused on changes in clinical characteristics in the asthmatic cohort. Significant reductions were observed in the mean frequency of events per 12 months – events comprising emergency room visits/urgent care visits for asthma (1.88 in baseline versus 0.40 in follow-up; $p < 0.05$), oral corticosteroid courses (1.11 in baseline versus 0.21 in follow-up; $p < 0.01$), hospitalisation for asthma (0.09 in baseline versus 0.00 in follow-up), and missed days due to asthma (3.86 in baseline versus 2.00 in follow-up; $p < 0.05$). Improvement in asthma control was specified as an increase in ACT score of 3 or greater, a decreased rate of emergency/urgent care visits, a decreased rate of oral corticosteroid courses, or a decrease in rescue short-acting beta2-agonists usage in the previous month. In terms of clinical outcomes, patients with fully controlled asthma were excluded. Not fully controlled asthma was characterised as pediatric ACT < 25, adult ACT < 23, one or more ED/urgent care visits in the previous year, one or more oral corticosteroid courses in the last year, or using SABA medication in the last month. In the cohort of asthmatic patients, there were 48 patients without fully controlled asthma. Of these 48 patients, 36 (75%) had an improvement in symptoms in at least one category after AT. When restricted to the 34 subjects with poorly controlled asthma at baseline, 29 individuals (85%) experienced an improvement in symptoms in at least one category [10].

In the study by Busino et al. [11], the study group consisted of 465 children who underwent adenotonsillectomy. Of this number, 93 had asthma while 372 did not have an asthma diagnosis. Outcome measures of asthma control were assessed during the 12 months preoperatively and 12 months postoperatively. They included hospital visits, systemic steroid use, asthma medication use, and scores on the Asthma Control Test (which are analysed later in this review). They observed a statistically significant reduction in the number of postoperative hospital visits ($p < 0.01$). Systemic steroid usage was significantly decreased postoperatively ($p < 0.01$). Medication usage also exhibited a significant decrease after surgery, with a notable reduction in the number of daily medications required per patient ($p < 0.01$) [11].

Goldstein et al. [12] performed a prospective, controlled study of asthma control in 80 asthmatic patients undergoing AT matched by sex, age, and asthma severity to a control group consisting of 62 patients not undergoing AT. Asthma outcomes were measured based on the count of asthma exacerbations, number of courses of systemic steroids, emergency room visits, and hospitalisations, over a period of 6 months. The median count of asthma exacerbations was 1 for both groups at the beginning and decreased to 0 for both groups during the follow-up period, along with median counts of other outcomes remaining at 0 at both the start and follow-up for both groups. When the analysis was limited only to patients with moderate or severe persistent asthma, there was an increase in the number of asthma exacerbations and courses of systemic steroids; however, each group consisted of only 8 patients. Due to the prevalence of 0 values, for analysis the asthma outcomes were split into 0 versus > 0. There were no significant differences between the groups at either time point for the occurrence of any asthma exacerbations (entry $p = 0.367$; follow-up $p = 0.327$), and both groups exhibited significant improvement over time (AT $p < 0.001$; control $p = 0.002$). Regarding use of any steroids, there were no significant group differences at entry ($p = 0.802$) but they differed at follow-up ($p = 0.043$). There was significant improvement over time in the AT group ($p < 0.001$) but not in the control group ($p = 0.083$). Concerning any emergency room visits, group differences were noted at entry ($p = 0.034$), but not at follow-up ($p = 0.053$). Both groups demonstrated significant improvement over time ($p = 0.005$ for both tests). For any hospitalisation, the groups differed significantly at entry ($p = 0.035$) but not at follow-up ($p = 0.347$) [12].

Improvement in asthma control scores

Three of the four studies included in the review used some form of a patient-reported questionnaire to obtain information about asthma control quality. Busino et al. [11]

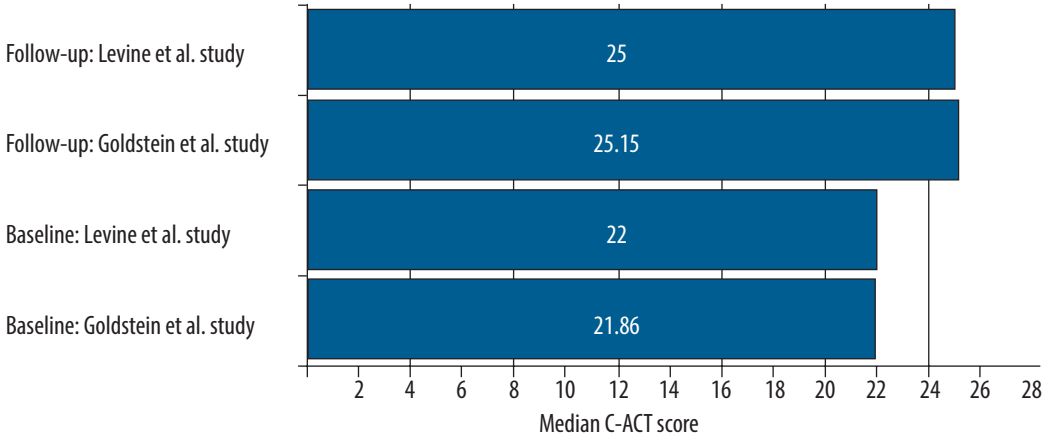

Figure 2. Median C-ACT scores in the studies by Goldstein et al. and by Levin et al.

used the Asthma Control Test (ACT) which is a validated and widely used tool designed to assess the level of asthma control. It consists of 5 questions, each answered with a number on a scale of 1 to 5. Total score ranges from 5 to 25, with higher scores indicating better asthma control.

Goldstein et al. [12] used the Childhood Asthma Control Test (C-ACT), which is a questionnaire designed to assess the level of asthma control in children aged 4 to 11 years [14]. It consists of 7 questions, 4 of which are answered by the child with the help of a parent, and 3 by the parent. Responses are summed to a score ranging from 0 (poor control of asthma) to 27 (complete control of asthma); a score ≤19 is defined as uncontrolled asthma [14]. Levin et al. [10] used both C-ACT and ACT for relatively older pediatric patients. In that case, ACT scores were rescaled from a maximum of 25 to 27, in order to compare them with C-ACT scores that also have a maximum score of 27.

Goldstein et al. [12] presented research material covering a group of 80 children with diagnosed asthma who were undergoing AT and 62 controls matched by age, sex, and asthma severity. They demonstrated significant improvement in C-ACT scores in asthmatic children after undergoing AT compared to asthmatic control children not undergoing the procedure. The adjusted mean entry C-ACT score for the AT group was 21.9 (20.9–22.7) and 22.4 (21.5–23.3) for the control group. The adjusted mean follow-up C-ACT score for the AT group was 25.2 (24.6–25.7) and 23.6 (22.8–24.3) for the control group. There was significant group-by-time interaction ($p < 0.001$). Their simple effects analysis showed that group means did not differ at entry ($p = 1.00$) but did differ at follow-up ($p = 0.006$). Some 47% of the AT group had C-ACT scores < 19 at entry, whereas only 15% had scores < 19 at follow-up after undergoing AT. In the control group, scores < 19 were obtained from 37% of patients at entry and 32% at follow-up [12]. The results are shown in **Figure 2**.

In their studies, Levin et al. [10] used pediatric ACT (C-ACT) for 46 patients and adult ACT for 5 patients. As mentioned earlier, ACT scores were rescaled to allow comparison with C-ACT scores. Some 15 of their asthmatic patients never completed baseline C-ACT. Baseline C-ACT scores ranged from 6 to 27 with a median of 22. In their studies, they also described a subgroup of patients with poorly controlled asthma. Key requirements were a C-ACT score below 20, ≥ 2 emergency department/urgent care visits in the last year, ≥ 2 oral corticosteroid courses in the last year, or use of short-acting bronchodilators more than twice per week in the last month. These requirements were met by 38 patients. Follow-up was achieved for 81% of all enrolled subjects ($n = 105$), 58 asthmatic patients, and 47 control patients. The mean time to follow-up was 7 months. There was a significant improvement in C-ACT scores at the follow-up visit, with the median score increasing from 22 to 25 ($p < 0.001$). In the case of the subgroup with poorly controlled asthma at baseline, the analysis of ACT scores after undergoing AT demonstrated a median increase of 6 ($p = 0.02$). An analysis of responses to C-ACT showed that there were noteworthy pairwise increases in responses to 6 of 7 questions. These included the child's self-assessment of asthma symptoms on that day (question 1; $p < 0.01$), cough (question 3; $p < 0.0001$), and nighttime symptoms (question 4; $p < 0.0001$). There were also significant pairwise increases in the three questions evaluated by parents (questions 5–7; frequency of daytime symptoms, $p = 0.0001$; frequency of wheeze, $p < 0.01$; and frequency of nighttime symptoms, $p < 0.001$) [10]. These results are also shown in **Figure 2**.

In the Busino et al. [11] study, they measured ACT scores of 93 asthmatic children 12 months pre-operatively and compared them to scores obtained from follow-up 12 months after the AT. They showed that ACT scores significantly improved following surgery (there was no comparison with a control group). The mean preoperative ACT score was 18.5 compared to 20.5 postoperatively. The results are shown in **Figure 3**. Overall, all of the studies using a patient-reported questionnaire to obtain information about asthma control quality consistently demonstrated improvements in such control tests.

Decreased level of asthma-related chitinase

The study by Levin et al. [10] focused on one additional aspect of monitoring asthma control: they measured chitinase activity in circulation on baseline and during

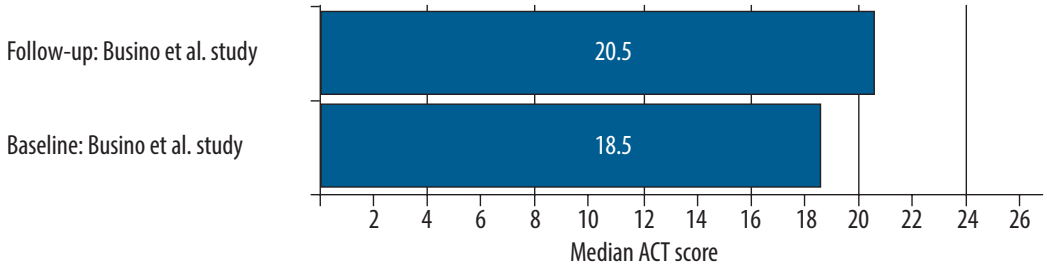

Figure 3. Median ACT scores in the study by Busino et al.

follow-up. Chitinase binds to or cleaves chitin, while many chitin-containing substances serve as common allergic triggers in asthma. Chitinase activity level is correlated with inflammation and disease activity in chronic diseases such as asthma [15]. Compared to subjects without concomitant upper airway disease, the actively enzymatic chitinase, chitotriosidase (CHIT1), exhibits overexpression in the adenoid tissue of children undergoing adenotonsillectomy because of concurrent chronic rhinosinusitis, otitis media with effusion, or allergic rhinitis [16]. Chitinase levels were assessed both at baseline and during follow-up. Children with asthma exhibited a significant reduction in circulating chitinase activity post-AT (median decrease of 0.4 nmol/l/ml*h, $p < 0.01$). Control group patients showed no significant change after surgery (median no change, $p = 0.83$). In the case of the asthmatic children, those with improved asthma control showed a notable decrease in chitinase activity following adenotonsillectomy ($p = 0.001$), while those without improvement showed no significant change ($p = 0.73$). Similar findings were observed in children with poorly controlled asthma: chitinase activity significantly decreased with improved asthma control (median decrease of 0.9 nmol/l/ml*h, $p < 0.01$), but remained unchanged when control was not improved (median no change, $p = 1.00$).

Discussion

In this review, we explored the impact of AT on asthma control in pediatric patients. The findings from the four included studies shed light on various aspects of asthma outcomes such as clinical outcomes, asthma control tests, and chitinase levels. The findings from the four studies confirm improvements after undergoing AT procedures, with three of the four showing significant enhancements in clinical outcomes.

Bhattacharjee et al. [9] reported a significant decrease in the occurrence of acute asthma exacerbations, acute status asthmaticus, asthma-related emergency room visits, and asthma-related hospitalisations. They also showed that AT+ patients experienced significant decreases in most classes of asthma prescriptions during the 1-year period following the procedure.

Levin et al. [10] demonstrated that 75% of patients had improvements in symptoms in at least one category, but when specifically considering the subgroup with poorly controlled asthma at baseline, 85% experienced improvements. This might indicate that in pediatric asthma the impact of AT on clinical outcomes depends on the severity of the initial asthma condition, emphasising the need for tailored interventions based on an individual's baseline asthma severity.

Busino et al. [11] revealed that both systemic steroid usage and the number of daily medications decreased after AT.

The Goldstein et al. [12] study demonstrated significant improvement in the primary outcome measure, the C-ACT score. But despite notable improvements in C-ACT scores, the study found minimal changes in asthma clinical outcomes. So, based on the C-ACT scores, patients demonstrated better self-reported asthma control, but this improvement did not translate into substantial changes in objective clinical measures of asthma. Given that 89% of AT+ patients, and 87% of control group patients, had intermittent or mild persistent asthma, the study acknowledges the limited number of outcomes. The distribution of asthma severity in the study population suggests there was a predominance of milder forms of asthma, and this might create difficulties in detecting clinical outcomes.

It is important to note that two of the four studies involved a control group consisting of asthmatic patients [9,12] while the two other studies included a control group involving non-asthmatic patients [10,11]. This raises important questions on the ability to reach firm conclusions about the impact of AT. Thus, an argument can be made for considering the natural history of the disease as a control group. This perspective provides a valuable reference point for interpreting the observed effects of AT. However, it is crucial to acknowledge the potential biases associated with using the natural disease course as a control group. All of the included studies using the Asthma Control Test (ACT) and Childhood Asthma Control Test (C-ACT) [10–12] consistently demonstrated improvements in asthma control postoperatively. The increase in scores present in all three studies supports the notion that AT positively affects the overall management of asthma in pediatric patients.

In the context of monitoring asthma control, the assessment of chitinase activity, as investigated by Levin et al. [10], provides a unique perspective on the molecular mechanisms associated with AT in pediatric patients with asthma. The fact that improved asthma control correlated with a significant decrease in chitinase activity emphasises the potential of AT to affect not only clinical manifestations but also the molecular markers associated with severe asthma.

This systematic review has limitations, and a critical evaluation is necessary for accurately interpreting the findings. The use of strong inclusion and exclusion criteria, while creating study rigor, resulted in a relatively small number of papers meeting the eligibility criteria. In our case, only 4 of an initial pool of 507 studies were deemed relevant. Moreover, assessing asthma outcomes after surgical intervention is complicated by the natural course of the disease. Because it is atopic, asthma may decrease or disappear in adolescence. We attempted to limit this bias by including studies with a maximum one-year follow-up after surgery. However, the limitation remains, and the long-term effects of adenoidectomy on asthma outcomes requires further investigation. Another problem with assessing information about asthma exacerbations is the fact that the presentation of this disease tends to increase during the winter months, coinciding with the prevalence of viral respiratory infections [17]. The inclusion of studies with varying follow-up durations might therefore inadvertently introduce biases related to the seasonal variation of symptoms. Future research should consider accounting for seasonal factors when evaluating the impact of surgical interventions on asthma outcomes.

Finally, it is noteworthy that while AT appears to positively affect asthma outcomes, the absence of AT from international asthma management guidelines – such as the Global Strategy for Asthma Management and Prevention (GINA) [5], the NICE guideline for diagnosis, monitoring, and chronic asthma management [18], and the Asthma Care Quick Reference prepared by the National Institutes of Health [19] – raises questions about recognising it as a standard intervention. The lack of inclusion of AT in international guidelines may stem from various factors, including insufficient high-quality evidence and the need for further research to elucidate its long-term outcomes. Addressing the gap between empirical evidence and guideline recommendations for AT in asthma management requires rigorous research studies, systematic reviews, and meta-analyses to provide robust evidence supporting its efficacy and safety. In conclusion, while the positive impact of AT on asthma outcomes is evident based on four included studies, its absence from international asthma management guidelines underscores the need for further research.

Conclusions

This systematic review highlights the potential benefits of adenotonsillectomy on asthma control in pediatric patients. The four included studies consistently demonstrated positive outcomes in terms of asthma control, with improvements observed in measures such as the Asthma Control Test, clinical outcomes, and chitinase levels.

Our analysis of the included studies suggests that AT contributes to a reduction in acute asthma exacerbations, emergency room visits, hospitalisations, and use of asthma medication. We also highlight the importance of considering the severity of initial asthma conditions, emphasising that the impact of AT on clinical outcomes may depend on the baseline severity of asthma.

Notably, the review highlights the molecular impact of AT, as evidenced by the assessment of chitinase activity. The correlation between improved asthma control and decreased chitinase activity suggests that AT not only influences clinical manifestations but also molecular markers associated with severe asthma.

In conclusion, despite indicating a positive impact, our study is limited by the small number of studies included in the qualitative synthesis. To fully understand the sustained effects of AT, the review emphasises the need for further research with longer follow-ups, case-matched controls, and seasonal considerations. It is essential to recognise the multifactorial nature of asthma exacerbations. Factors contributing to the natural course of asthma and its exacerbations should be carefully considered in future research. The findings of this review provide valuable insights for clinicians working towards innovative management strategies and support the rationale behind adenotonsillectomy as an intervention for asthma in pediatric patients.

References

1. Brozek G, Lawson J, Shpakou A, Fedortsiv O, Hryshchuk L, Rennie D, et al. Childhood asthma prevalence and risk factors in three Eastern European countries – the Belarus, Ukraine, Poland Asthma Study (BUPAS): an international prevalence study. BMC Pulm Med, 2016; 16(1): 11. https://doi.org/10.1186/s12890-016-0172-x
2. Damps-Konstańska I, Jassem E, Niedoszytko M. NFZ o zdrowiu. Astma. [in Polish]. Available from: https://ezdrowie.gov.pl/portal/home/badania-i-dane/zdrowe-dane/raporty/nfz-o-zdrowiu-astma [Accessed 14.12.2023].
3. Instytut Zarządzania w Ochronie Zdrowia. Astma oskrzelowa: nowy model zarządzania chorobą nakierowany na wzrost wartości zdrowotnej. [in Polish]. Available from: https://koalicja.pta.med.pl/wp-content/Astma_Raport_FINAL.pdf [Accessed 14.12.2023].
4. Samoliński B, Sybilski AJ. Znaczenie stanów zapalnych błony śluzowej nosa w astmie oskrzelowej. Współistnienie ANN i astmy oskrzelowej. Alergia Astma Immunologia, 2007; 12(1): 7–14 [in Polish].
5. Global Initiative for Asthma. 2022 GINA Report. Global Strategy for Asthma Management and Prevention. USA: WHO; 2022, p. 255. Available from: https://ginasthma.org/gina-reports/ [Accessed 14.12.2023].
6. Lis T, Zawadzka-Głos L. Adenoidectomy and adenotonsillotomy in patients treated in the Department of Paediatric Otorhinolaryngology of the Medical University of Warsaw in 2018: a retrospective analysis. New Medicine, 2019; 2: 43–8. https://doi.org/10.25121/NewMed.2019.23.2.43
7. Rosenfeld RM, Green RP. Tonsillectomy and adenoidectomy: changing trends. Ann Otol Rhinol Laryngol, 1990; 99(3): 187–91. https://doi.org/10.1177/000348949009900305
8. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ, 2021; 372(71). https://doi.org/10.1136/bmj.n71
9. Bhattacharjee R, Choi BH, Gozal D, Mokhlesi B. Association of adenotonsillectomy with asthma outcomes in children: a longitudinal database analysis. PLoS Med, 2014; 11(11): e1001753. https://doi.org/10.1371/journal.pmed.1001753

10. Levin JC, Gagnon L, He X, Baum ED, Karas DE, Chupp GL. Improvement in asthma control and inflammation in children undergoing adenotonsillectomy. Pediatr Res, 2014; 75(3): 403–8. https://doi.org/10.1038/pr.2013.237
11. Busino RS, Quraishi HA, Aguila HA, Montalvo E, Connelly P. The impact of adenotonsillectomy on asthma in children. Laryngoscope, 2010; 120 (Suppl. 4): S221. https://doi.org/10.1002/lary.21688
12. Goldstein NA, Thomas MS, Yu Y, et al. The impact of adenotonsillectomy on pediatric asthma. Pediatr Pulmonol, 2019; 54(1): 20–6. https://doi.org/10.1002/ppul.24207
13. Nathan RA, Sorkness CA, Kosinski M, Schatz M, Li JT, Marcus P, et al. Development of the asthma control test: a survey for assessing asthma control. J Allergy Clin Immunol, 2004; 113(1): 59–65. https://doi.org/10.1016/j.jaci.2003.09.008
14. Liu AH, Zeiger R, Sorkness C, Mahr T, Ostrom N, Burgess S, et al. Development and cross-sectional validation of the Childhood Asthma Control Test. J Allergy Clin Immunol, 2007; 119(4): 817–25. https://doi.org/10.1016/j.jaci.2006.12.662
15. Ober C, Chupp GL. The chitinase and chitinase-like proteins: a review of genetic and functional studies in asthma and immune-mediated diseases. Curr Opin Allergy Clin Immunol, 2009; 9(5): 401–8. https://doi.org/10.1097/ACI.0b013e3283306533
16. Heo KW, Hur DY, Park SK, Yang YI, Kwak HH, Kim TY. Expression of chitinases in hypertrophied adenoids of children. Otolaryngol Head Neck Surg, 2011; 145(4): 660–5. https://doi.org/10.1177/0194599811410656
17. Link HW. Pediatric asthma in a nutshell. Pediatr Rev, 2014; 35(7): 287–98. https://doi.org/10.1542/pir.35-7-287
18. National Institute for Health and Care Excellence (NICE). Asthma: diagnosis, monitoring and chronic asthma management. Available from: https://www.nice.org.uk/guidance/ng80/resources/asthma-diagnosis-monitoring-and-chronic-asthma-management-pdf-1837687975621 [Accessed 5.04.2024].
19. National Heart, Lung, and Blood Institute (NHLBI). Asthma Care Quick Reference. Available from: https://www.nhlbi.nih.gov/files/docs/guidelines/asthma_qrg.pdf [Accessed 5.04.2024].

Original articles

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SPEECH PERCEPTION IN NOISE IN MALAYALAM-SPEAKING YOUNG ADULTS WITH NORMAL HEARING

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Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

Abstract

Introduction: Various types of noise have been used with speech material to assess speech perception in noise (SPIN) abilities. The literature suggests that speech identification varies with different types of background noise, and it has been reported that the target native language and the language of the babbling influence performance. Such efforts in an Indian context have not yet been reported. The aim of the study is to evaluate the speech perception in noise performance of Malayalam-speaking young adults with normal hearing using three different background noises.

Material and methods: A repeated measure research design were adopted with a random sampling method. 30 native Malayalam speakers with normal hearing between the ages of 18 and 25 participated in the study. A standardized sentence list in Malayalam was used as the speech stimulus. Nine lists were chosen and randomly divided so that there were three lists to each background noise. Noises were speech spectrum-shaped noise, non-native language multi-talker babble (Kannada), and native language multi-talker babble (Malayalam). Each successfully repeated keyword received a '1' and each incorrectly repeated word received a '0.' Because each sentence had four important words, each collection of 10 sentences scored a maximum of 40. The percentage of correct answers was determined and further analyzed.

Results: Scores were significantly different in all three different background noises across different SNRs. The highest scores were obtained at +5 dB SNR and the poorest scores at –5 dB SNR. Among the three different background noises, native multi-talker babble (Malayalam) yielded better scores than non-native multi-talker babble (Kannada), followed last by speech spectrum-shaped noise.

Conclusions: The findings of the current study may be attributed to the increased efficacy of speech spectrum noise due to its energetic masking characteristics and the similarity between the two languages in terms of its origin and acoustic-phonetic properties.

Keywords: speech recognition • speech identification in noise • speech perception in noise • SPIN • non-native speech

PERCEPCJA MOWY W SZUMIE U MŁODYCH DOROSŁYCH Z PRAWIDŁOWYM SŁUCHEM MÓWIĄCYCH W JĘZYKU MALAJALAM

Streszczenie

Wstęp: Do oceny percepcji mowy w hałasie (SPIN) wykorzystuje się różne rodzaje szumu tła. Wyniki badań opisane w literaturze przedmiotu sugerują, że identyfikacja mowy w szumie różni się w zależności od rodzaju szumu, w tym od tego, czy jest to szum mowy ojczystej czy obcojęzycznej. W Indiach do tej pory nie były prowadzone tego typu badania. Celem pracy jest ocena percepcji mowy w hałasie u młodych dorosłych ze słuchem w normie, mówiących w języku malajalam, z wykorzystaniem trzech różnych szumów tła.

Materiał i metody: W badaniu zastosowano metodę powtarzanego pomiaru z losowym doborem próby. W badaniu wzięło udział 30 rodzimych użytkowników języka malajalam ze słuchem w normie, w wieku od 18 do 25 lat. Bodźcem mowy były opracowane listy zdań w języku malajalam. Wybrano dziewięć list i podzielono je losowo, tak aby na każdy szum tła przypadały trzy listy. Jako szumy tła wybrano: szum dopasowany do widma mowy, szum mowy obcojęzycznej (kannada) i szum mowy w języku ojczystym (malajalam). Każde prawidłowo powtórzone słowo z listy zdań otrzymywało „1", a każde niepoprawnie powtórzone – „0". Ponieważ każde zdanie zawierało cztery istotne słowa, za każdy zbiór 10 zdań można było uzyskać maksymalnie 40 punktów. Określono procent poprawnych odpowiedzi i poddano dalszej analizie.

Wyniki: Wyniki były znacząco różne dla wszystkich trzech szumów tła przy różnych wartościach SNR. Najwyższe wyniki uzyskano przy SNR +5 dB, a najniższe przy SNR –5 dB. Spośród trzech różnych szumów tła, wyniki dla szumu mowy w języku rodzimym (malajalam) były lepsze niż wyniki dla szumu mowy obcojęzycznej (kannada), a te z kolei były lepsze niż dla szumu dopasowanego do widma mowy.

Wnioski: Zaobserwowano podobieństwo między dwoma językami uwzględnionymi w badaniu (malajalam i kannada), prawdopodobnie ze względu na podobne właściwości akustyczno-fonetyczne obu języków i znajomość języka nierodzimego.

Słowa kluczowe: rozpoznawanie mowy • identyfikacja mowy w szumie • percepcja mowy w szumie • SPIN • mowa obcojęzyczna

Key for abbreviations

ANSI	American National Standards Institute
FFT	fast Fourier transform
LTSSN	long-term speech-shaped noise
MTB	multi-talker babble
NMTB	native multi-talker babble
NNMTB	non-native multi-talker babble
PTA	pure tone averages
SCAP-A	Screening Checklist for Auditory Processing in Adults
SIN	speech-in-noise
SIS	speech identification scores
SNR	signal-to-noise ratio
SPIN	speech perception in noise
SRT	speech recognition thresholds
SSN	speech spectrum noise

Introduction

Speech perception in noise (SPIN) testing can reveal important information about a patient's auditory system. It has the potential to be used in diagnosing and evaluating the hearing system's functional capability, providing clinicians with extremely useful information while needing very little clinical time. A SPIN test can provide important information concerning real-world complaints for these patients. The measurement of speech perception provides useful information in assessing communication difficulties experienced by listeners. The scope of speech perception tests extends to the assessment and monitoring of communication difficulties experienced by listeners [1]. A variety of test materials such as nonsense syllables, monosyllables, bisyllables, and sentences are used to assess the speech perception abilities of individuals [2].

Over the years, different forms of sentence tests have been developed, keeping in mind the perceptual difficulties of those with hearing loss and the language of the individual [3]. Studies reported that the mother tongue of an individual affects his or her perception of speech and that participants consistently have better discrimination scores in their mother tongue compared to other languages [3]. Numerous tests can be used to determine whether or not someone understands speech in a noisy environment. Any listener, particularly those with hearing problems, faces a significant barrier in understanding speech in background noise. Because of the difficulty this exercise presents to listeners, it can provide valuable insight into an individual's capacity to cope with regular everyday listening conditions, which are frequently noisy [4]. Researchers have found that people with hearing impairment need a higher SNR (10–15 dB) than people with normal hearing. With the increase in SNR, a hearing-impaired person's ability to recognize speech increases by about 3% [5]. Therefore, it has been found that the addition of noise to the SIN perception test increases the sensitivity and specificity of the test; by adding multiple noises, the difficulty of the perception increases and the possibility of differentiating people with normal hearing from people with hearing impairment improves [6]. Hence, it is important to have speech material in the mother tongue of an individual.

There have been some attempts in the literature to compare speech perception in the presence of noise across different types of background noises. However, a comprehensive evaluation of differences in speech identification across native language multi-talker babble, non-native language multi-talker babble, and speech spectrum-shaped noise are few in the Indian context.

Various types of noise have been used with speech material to assess speech perception in noise abilities. Earlier findings in a study of English phrase recognition in quiet and two types of maskers, multi-talker babble (MTB) and long-term speech-shaped noise (LTSSN), with varying signal-to-noise ratios for English-, Chinese-, and Korean-native listeners. The test results showed that background noise affected non-native listeners' sentence recognition more than native listeners [5]. Sentence recognition in native- and foreign-language multi-talker background noise has been studied by some researchers [7]. This study looked at speech-in-noise detection when the background noise language was the same as or different from the target speech language. Regardless of the language of the babbling, native English listeners had a harder time understanding English sentences in six-talker babble than in two-talker babble. Furthermore, their results showed that native English listeners were more negatively influenced by English babble than Mandarin Chinese babbling in two-talker babble [7]. These findings show "linguistic interference" as a sort of informational masking on sentence-in-noise detection. Thus, the evidence suggests that speech identification varies with different types of background noise. However, it is reported that the native language and the language of babbling influence the performance. Researchers have also noted the interaction effect of gender and ear laterality in quiet and at different SNRs are not significant [8]. Nevertheless,

Table 1. Demographic details of the participants

Number of participants	30
Age range	18–25 years
Mean age	22.4 years
Male: female distribution	15:15
Education	undergraduate university students

such attempts in the Indian context have not yet been reported in the literature.

Hence, the present study was proposed to evaluate the SPIN performance in Malayalam-speaking young adults with normal hearing abilities using three different background noises: speech spectrum-shaped noise, non-native language (Kannada) multi-talker babble, and native language (Malayalam) multi-talker babble.

The aim of the study is to evaluate the speech perception in noise performance in Malayalam-speaking young adults with normal hearing abilities using three different background noises. To compare the SPIN performance in Malayalam-speaking young adults with normal hearing abilities using different background noises such as speech spectrum-shaped noise, non-native language multi-talker babble, and native language multi-talker babble.

Material and methods

Approval to conduct the study was obtained from the Research Advisory Committee of the JSS Institute of Speech and Hearing in January 2022. The study was carried out in four phases as follows.

Phase 1: Participant selection

A repeated measure research design was adopted with a random sampling method. A total of 30 participants between the ages of 18 to 25 years were chosen. Prior written and oral consent was obtained from all the participants and their capacity to distinguish speech from background noise was tested. The demographic details of the participants are provided below in **Table 1**. All the participants had bilateral normal hearing sensitivity (PTA < 15 dB HL; SRT +10 dB of PTA; SIS > 90%; ANSI, 1996) and normal auditory processing abilities, assessed using Screening Checklist for Auditory Processing in Adults (SCAP-A). All participants were native Malayalam speakers. Participants with any history of middle ear pathology or neurological, psychological, visual, or behavioural problems were excluded.

Phase 2: Preparation of different background noises

PRAAT software was used to record a 2-minute 4-talker speech jumble. The method for recording speech babble was adapted from another study [2]. Native language multi-talker babble was recorded in a classroom setting, with four native Malayalam speakers seated in a circle configuration in the centre of the room using an Omni directional microphone. The distance between the microphone and each speaker's mouth was approximately 30 cm. Speakers were instructed to read a variety of Malayalam newspaper articles at the same time. They were told to keep their speech loud and rate at standard conversational levels. The recorded speech babble was saved in the WAV file on a PC. The level of the recorded voice babble was later standardized to 70 dB SPL using PRAAT.

The same procedure was adapted to record non-native language multi-talker babble. Speakers were instructed to read a variety of Kannada newspaper articles at the same time. For recording speech spectrum-shaped noise, all of the selected audio samples of sentences were concatenated in random order, and a fast Fourier transform (FFT) was conducted separately for each language on these concatenated sentences. To generate back auditory speech noise signal, a reverse FFT with random phase was generated using the obtained spectral values. As a result, the noise generated had a frequency spectrum that was similar to the selected words' long-term average spectrum. The recorded background noises were added to the speech stimuli. The reasoning behind this was that a matched noise would mimic the actual form of noise that would disguise speech in a real-life circumstance [3]. The RMS level of the generated noise was matched to the same level as the sentences.

The Malayalam sentences for the speech stimuli were taken from the sentence list in Malayalam and Telugu [9]. The test consists of 16 lists with 10 sentences each. The phoneme frequency in each list correlated with the overall phoneme frequency from another study [10]. This maintained the phonemic balance throughout all created sentence lists. The same procedure was adopted for adding the three different background noises to the speech stimuli in the present study. A total of nine lists were selected and it was randomly divided so that three lists were added to native talker babble non-native talker babble and speech spectrum-shaped noise respectively. Matlab software (v. R2017a) was used to add three different types of noise. Within the divided list, background noises were added at three different SNR levels (i.e. at +5, 0, and –5 dB SNR) for each list.

Phase 3: Assessing speech perception in noise ability

The experiment was carried out in a well-lit, acoustically treated room. The sentences of each list were randomly presented to each participant through the headphones (Sennheiser HD 202) attached to the personal computer (HP Pavilion core i-3 processor). The output of the headphones was monitored using the sound level meter (B & K-2238, mediator). The stimuli were presented binaurally at 70 dB SPL loudness level (the most comfortable loudness level). The stimuli were delivered in a binaural format. The participants were advised to pay close attention to the sentences and repeat each word. The participants' responses were captured using an audio recorder for further analysis.

Phase 4: Analysis of data

Each successfully repeated keyword received a score of '1', whereas each mistakenly repeated word received a score of '0.' Any response with a glaring error was regarded as

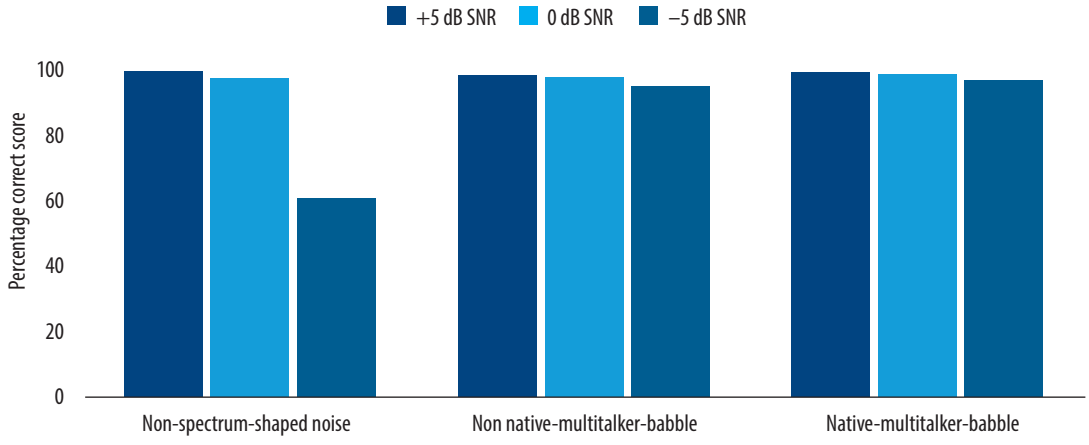

Figure 1. Mean percentage scores with different background noises

Table 2. Mean percentage and standard deviation of scores obtained at different SNRs across the background noises

SNR levels	Speech spectrum noise	Non-native multi-talker babble	Native multi-talker babble
+5 dB SNR	99.25 (*SD* = 5.20)	99.25 (*SD* = 2.84)	99.67 (*SD* = 1.34)
0 dB SNR	97.83 (*SD* = 1.63)	98.58 (*SD* = 1.34)	99.25 (*SD* = 1.08)
–5 dB SNR	61.15 (*SD* = 13.51)	95.58 (*SD* = 3.70)	97.25 (*SD* = 3.17)

Table 3. Friedman test results for comparison of speech perception in noise at different SNRs

Background noises	Friedman test values across the SNRs
Speech spectrum-shaped noise	$\chi^2 = 53.38$, $p < 0.001$
Non-native multi-talker babble	$\chi^2 = 28.22$, $p < 0.001$
Native multi-talker babble	$\chi^2 = 19.31$, $p < 0.001$

Table 4. Friedman test results for comparison of speech perception in noise at different background noises

SNR levels	Friedman test values across the background noises
+5 dB SNR	$\chi^2 = 4.85$, $p = 0.09$
0 dB SNR	$\chi^2 = 1.09$, $p = 0.58$
–5 dB SNR	$\chi^2 = 51.71$, $p < 0.001$

Table 5. Wilcoxon signed rank test values across the background noises between the SNRs

SNR comparison	Speech spectrum noise	Non-native multi-talker babble	Native multi-talker babble
0 dB and +5 dB	$Z = -2.14$, $p < 0.001$	$Z = -1.49$, $p = 0.14$	$Z = -1.25$, $p = 0.21$
+5 dB and –5 dB	$Z = -4.79$, $p < 0.001$	$Z = -4.18$, $p < 0.001$	$Z = -3.21$, $p < 0.001$
0 dB and –5 dB	$Z = -4.79$, $p < 0.001$	$Z = -3.46$, $p < 0.001$	$Z = -3.16$, $p < 0.001$

an incorrect response solely. Each sentence contained four keywords and hence, each list with 10 sentences received a maximum score of 40. Scores obtained were converted to percentage correct scores and further statistical analysis was carried out using the SPSS version 21 statistical software.

Results

In the present study, speech-in-noise scores obtained using different types of noises were compared across three different SNRs: +5 dB SNR, 0 dB SNR, and –5 dB SNR (**Figure 1**). Shapiro–Wilk test was used to assess normality and found that data were non-normally distributed. Friedman test was carried out for further analysis. Further, post hoc analysis was carried out using the Wilcoxon signed ranks test to compare between the SNRs and background considered.

The mean percentage correct scores thus obtained in the presence of speech spectrum noise (SSN), non-native multi-talker babble (NNMTB), and native multi-talker babble (NMTB) at +5 dB SNR, 0 dB SNR, and –5 dB SNR are shown in **Table 2**. A Friedman test for comparison of speech perception in noise at different SNRs (using speech spectrum-shaped noise, NNMTB, and NMTB

as background noise) showed significant differences, as shown in **Table 3**.

Similarly, the speech recognition scores were then compared across different types of noises at equivalent SNRs. The comparison of SPIN across different types of background noise at +5 dB SNR and 0 dB SNR showed no significant difference. However, the comparison of SPIN across different types of background noise at –5 dB SNR showed a significant difference as shown in **Table 4**.

Further, Wilcoxon signed ranks test was carried out to test significance between the categories. The results revealed that there was a significant difference between all three categories while using speech spectrum-shaped noise but the similar trend was not seen in non-native multi-talker babble and native multi-talker babble as shown in **Table 5**.

Speech perception scores were better at +5 dB SNR than 0 dB SNR followed by –5 dB SNR using non-native multi-talker babble, native multi-talker babble and speech shaped noise. Thus, in all three noise conditions, the highest scores were obtained at +5 dB SNR and the poorest scores at –5 dB SNR.

Discussion

The present study aimed to examine the scores of Malayalam-speaking young adults with normal hearing abilities for speech perception in noise utilizing speech spectrum-shaped noise, non-native language multi-talker babble, and native language multi-talker babble. The percentage of correct answers was determined and then further analysed. The results of the present study are in agreement with the previous studies [1,12,13].

Sentence recognition in native- and foreign-language multi-talker background noise was reported in an earlier study [9]. The aim of the study was to determine whether the adverse effect of background speech is due to the linguistic content or to the acoustic characteristics of the speech masker. According to the results, in every situation, better target sentence perception was produced by greater SNRs. As the level of noise increases relative to the target, the ability to hear speech declines. The results of the present study are in agreement with the previous studies [1,12,13] in all three noise conditions, used in the present study, i.e., speech spectrum-shaped noise, non-native multi-talker babble, and native multi-talker babble, the highest scores were obtained at +5 dB SNR and the poorest scores at –5 dB SNR. The higher the signal-to-noise ratio, the more intense will be the signal. When the speech signal has a higher intensity than the background noise, it helps in better identification of speech. But as the signal intensity decreases, background noise will mask the signal, which in turn affects speech perception.

In the present study among all the three different background noises, native multi-talker babble yielded better scores than non-native multi-talker babble followed by speech spectrum-shaped noise. At higher SNRs however, there was no difference across the different background noise. But, as the SNR decreased to –5 dB SNR, speech perception scores using multi-talker babble were better than speech spectrum-shaped noise. These improved scores for multi-talker babble were reported by an earlier study [11]. Better scores with native multi-talker babble than non-native multi-talker babble is also reported in the literature [9]. This can be attributed to the similarity between the two languages included in the study as they have a common origin. The similarity between the two languages' acoustic-phonetic properties or acquaintance with the non-native tongue would have determined this. Additionally, a cognitive component would come into play, where individuals would get more easily distracted by a foreign language in the background as opposed to a familiar one.

Thus, the present study showed that the performance of speech recognition was better when multi-talker babble was used when compared to the speech-shaped noise. Speech spectrum-shaped noise provides the same long-term average signal-to-noise ratio (SNR) in each frequency band. Hence, there is no gap within the noise generated and it provides energetic masking which effectively masks the speech signal. Moreover, when the multi-talker babbles were compared, the NNMTB was found to be a more effective masker than the NMTB. This finding may be attributed to the similarity in the origin (Dravidian) of both languages used in the current study. Moreover, the performance was found to be progressively poorer with reducing SNRs.

Conclusions

In the current study, for all three background noises speech recognition scores were better at +5 dB SNR and poorer at –5 dB SNR. Among the background noises, speech perception was found to be better when using native multi-talker babble (Malayalam) than non-native (Kannada) multi-talker babble, followed last by speech spectrum-shaped noise. Native talker-babble may provide acoustic cues which ease the perception of speech in noise compared to other background noises. The similarity between the two investigated languages – because of their common Dravidian origin – could be the cause of this difference. Alternatively, listeners may get easily distracted by a foreign language in the background as opposed to a familiar one. The present study findings warrant further research on the influence of native and non-native multi-talker babble on speech in noise perception using various native and non-native language combinations.

Limitations

The study was carried out using a small sample size. The study considered only young normal adults.

Future directions

The present study was based on a small sample size, and the study could be carried out with a larger population and with other age groups. It could also be studied using a clinical population.

References

1. Gundmi A, Himaja P, Dhamani A. Effectiveness of multi-talker babble over speech noise and its implications: a comparative study. Indian J Otol, 2018; 24(2): 88. https://doi.org/10.4103/indianjotol.indianjotol_24_18
2. Killion MC, Niquette PA, Gudmundsen GI, Revit LJ, Banerjee S. Development of a quick speech-in-noise test for measuring signal-to-noise ratio loss in normal-hearing and hearing-impaired listeners. J Acoust Soc Am, 2004: 116(4): 2395–405. https://doi.org/10.1121/1.1784440
3. Prosser S, Turrini M, Arslan E. Effects of different noises on speech discrimination by the elderly. Acta Otolaryngol, 1991; 111 (Suppl 476): 136–42. https://doi.org/10.3109/00016489109127268
4. Taylor B. The acceptable noise level test as a predictor of real-world hearing aid benefit. Hear J, 2008; 61(9): 39–40, 42. https://doi.org/10.1097/01.HJ.0000339505.97796.a9
5. McArdle R, Hnath-Chisolm T. Speech audiometry. In: Katz J, Chasin M, English K, Hood LJ, Tillery KL, editors. Handbook of Clinical Audiology. 7th edition. Philadelphia: Wolters Kluwer; 2015, p. 61–76.
6. Bamiou DE, Iliadou VV, Zanchetta S, Spyridakou C. What can we learn about auditory processing from adult hearing questionnaires? J Am Acad Audiol, 2015; 26(10): 824–37. https://doi.org/10.3766/jaaa.15009
7. Jin SH, Liu Ch. English sentence recognition in speech-shaped noise and multi-talker babble for English-, Chinese-, and Korean-native listeners. J Acoust Soc Am, 2012; 132(5): EL391–7. https://doi.org/10.1121/1.4757730
8. Jain C, Kodanath S, Vimal BM, Suresh V. Influence of native and non-native multitalker babble on speech recognition in noise. Audiol Res, 2014; 4(1): 89. https://doi.org/10.4081/audiores.2014.89
9. Amiri M, Mohammadi M, Razavi SZ, Abdollahi H, Iran Pour Mobarakeh Z. Normative data for speech-in-noise perception test in young adults with normal hearing: gender and ear laterality effects. Aud Vestib Res, 2023; 32(1): 64–9. https://doi.org/10.18502/avr.v32i1.11323
10. Ramakrishna BS, Nair KK, Chiplimear VN, Atal BS, Ramachandran V, Subramanian R. Some aspects of the relative efficiencies of Indian languages. Department of Electrical Communication Engineering, Indian Institute of Science, Bangalore, 1962.
11. Van Engen KJ, Bradlow AR. Sentence recognition in native- and foreign-language multi-talker background noise. J Acoust Soc Am, 2007; 121(1): 519–26. https://doi.org/10.1121/1.2400666
12. Shojaei E, Ashayeri H, Jafar Z, Zarrin Dast MR, Kamali K. Effect of signal to noise ratio on the speech perception ability of older adults. Med J Islam Repub Iran, 2016; 30: 342.
13. Razak A, Thurston EJ, Gustainis LE, Kidd G, Swaminathan J, Perrachione TK. Talker identification in three types of background noise. J Acoustic Soc Am, 2017; 141(5): 4039. https://doi.org/10.1121/1.4989326

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ELECTROPHYSIOLOGICAL MEASURES OF AUDITORY IMPAIRMENT IN NOISE-EXPOSED, NORMAL-HEARING SOLDIERS

Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

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Abstract

Introduction: Some electrophysiological changes can occur in the auditory system in response to noise exposure with or without any permanent auditory threshold shift. The purpose of this study was to identify and measure cochlear function after noise exposure in individuals with normal hearing according to standard audiometric thresholds.

Material and methods: Pure tone audiometry (PTA) over the standard 0.250–8 kHz range and at 12 kHz, as well as distortion product otoacoustic emission (DPOAE) and auditory brainstem response (ABR) testing, were performed on 42 soldiers who had participated in combat. A control group of 40 participants underwent the same tests.

Results: In the noise-exposed group, significantly poorer PTA thresholds were recorded at 12 kHz. DPOAE levels were significantly low only at 4 kHz. On ABR testing, both wave I and wave V demonstrated a significant decrease in amplitude and a significant increase in latency for the noise-exposed group.

Conclusions: Our findings reveal that high levels of noise can not only damage outer hair cells but also cause changes at the level of the synapses (synaptopathy) which are not evident using standard PTA tests. However, electrophysiological methods can detect some changes in cochlear function.

Keywords: DPOAE • ABR • noise exposure • cochlear synaptopathy

ELEKTROFIZJOLOGICZNE POMIARY UPOŚLEDZENIA SŁUCHU U NARAŻONYCH NA HAŁAS ŻOŁNIERZY ZE SŁUCHEM W NORMIE

Streszczenie

Wstęp: W układzie słuchowym mogą wystąpić pewne zmiany elektrofizjologiczne w reakcji na hałas skutkujące lub nie stałym przesunięciem progu słyszenia. Celem tego badania było zidentyfikowanie i zmierzenie funkcji ślimaka po narażeniu na hałas u osób ze słuchem w normie zgodnie ze standardowym progami audiometrycznymi.

Materiał i metody: W grupie 42 żołnierzy, którzy uczestniczyli w walce, wykonano następujące badania: audiometrię tonalną (PTA) w standardowym zakresie 0.250–8 kHz oraz dla 12 kHz, pomiar emisji otoakustycznych produktów zniekształceń nieliniowych (DPOAE), a także słuchowych potencjałów wywołanych pnia mózgu (ABR). Grupa kontrolna złożona z 40 osób przeszła te same testy.

Wyniki: W grupie narażonej na hałas zanotowano: statystycznie istotne pogorszenie progów PTA dla 12 kHz, poziomy DPOAE były istotnie obniżone tylko dla 4 kHz, w teście ABR zarówno fala I jak i fala V miały istotnie obniżoną amplitudę i istotnie opóźnioną latencję.

Wnioski: Nasze wyniki pokazują, że duży poziom hałasu może nie tylko uszkadzać zewnętrzne komórki rzęsate, lecz także powodować na poziomie synaps (synaptopatia) szkody, które nie są widoczne w standardowym badaniu PTA. Jednak metody elektrofizjologiczne mogą wykryć pewne zmiany w funkcjonowaniu ślimaka.

Słowa kluczowe: DPOAE • ABR • narażenie na hałas • synaptopatia ślimakowa

Introduction

Prolonged exposure to loud noise can cause tinnitus and hearing loss. It has long been assumed that the key indicator of noise-induced hearing loss was outer hair cell death [1]. Work in animal models has demonstrated that in noise-induced hearing loss such exposures cause only reversible threshold shifts (and no hair cell loss); however, they did result in the permanent loss of > 50% of cochlear nerve/hair cell synapses [2]. In humans, on study found that after a high level of voluntary noise exposure background (NEB), wave I of the auditory brainstem response (ABR) had reduced amplitude but there was normal hearing in response to suprathreshold clicks and 4 kHz tone bursts [3]. However, damage was only apparent when ABR wave I amplitude was examined. In contrast, distortion product otoacoustic emission (DPOAE) levels were found not to be significantly changed in the context of NEBs [3]. The suprathreshold ABR wave I amplitude was also lower in veterans reporting high levels of military noise exposure and in nonveterans reporting a history of firearm use than in veterans and nonveterans with lower levels of reported exposure [1]. Otoacoustic emissions (OAEs) have been described in some studies as early indicators of noise-induced damage or as a method to determine potential risks for developing noise-induced hearing loss [4–6]. Some reports, however, have not supported a significant role for OAEs in this regard [7].

Noise-induced cochlear synaptopathic injury cannot be detected by conventional audiometric assessment of threshold sensitivity. Thus, potential damage to auditory health and the performance consequences of noise-induced cochlear synaptopathic injury can be easily overlooked, especially if loss of threshold is the major concern [8]. When compared with behavioural threshold assessment, the use of DPOAEs in ears with normal thresholds (≤ 20 dB nHL) is not strongly supported as a way of detecting noise damage at an early stage [5–7]. In general, it seems that factors like ear side and gender have only minor effects on both DPOAEs and hearing thresholds in both the standard and extended high frequency ranges [9]. They confirm that hearing thresholds and DPOAEs in the extended frequency audiometry band seem to show promise for identifying early signs of hearing loss. Both EHFA and DPOAEs provide early evidence of noise-induced hearing loss in young recreational firearm users [10].

The purpose of our study was to assess cochlear function in normal hearing subjects after noise exposure in combat, giving insight into outer hair cell function and synaptopathy.

Material and methods

After the approval of the YSMU Science Coordination Council (19/02/2021, Nr. 1), 42 male subjects (84 ears) aged 20 to 39 years (mean age = 22.7 years) who had participated in combat in 2020 were involved in our study. The total duration of the military action lasted for 44 days, and the subjects had not previously participated in such events. Our study also excluded any acoustic trauma incidents prior to the combat. During combat they were constantly exposed to different forms of potentially harmful noise. All participants gave permission to participate. The study inclusion criteria were as follows: hearing threshold at in the range 0.25–8 kHz ≤ 20 dB hearing level (HL) (normal range according to BIAP) [11], normal middle ear function, absence of any contemporary hearing reduction during or after the war, and absence of any subjective hearing loss. The middle ear was evaluated by otoscopy and tympanometry (GSA Tympstar Pro), and was considered within normal limits if categorised as Type A by the Jerger classification [12]. As a control group, 40 male peers (79 ears, because one participant had unilateral otitis media at the time of the study) aged 19–41 years (mean age = 22.9 years old) were chosen. The inclusion criteria for the control group were a hearing threshold of ≤ 20 dB HL from 0.25 to 8 kHz, normal middle ear function, and no previous long-term, high-level noise exposure.

The participants of our study underwent the following audiological testing for cochlear function in Nairi MC:

- Pure tone audiometry (PTA) over the conventional 0.25–8 kHz range and at one extended high-frequency only at 12 kHz (examination at higher frequencies was not possible due to limitations of the audiometer). Hearing thresholds were determined for air conduction (GSI Audiostar Pro) and measurements were made in a sound proof cabin.
- Recording of the discomfort threshold in the 0.25–12 kHz range. Normal-hearing individuals have loudness discomfort level (LDL) between 86 and 98 dB HL for 0.5–8 kHz stimuli [13,14]. Thus discomfort threshold was evaluated at every frequency starting from 80 dB HL and increasing the intensity until the patient reported discomfort (GSI Audiostar Pro).
- DPOAE testing (2f1–f2 DP-gram, L1 = 65 dB sound pressure level (SPL), L2 = 55 dB SPL, f2/f1 = 1.22, SNR ≥ 6 dB, DP stability ± 2 dB); DP-gram responses were analyzed at 1, 2, 4, 6, and 8 kHz. Measurements were made in a sound proof cabin. If needed, testing was repeated several times until there was no difference among the two groups in terms of noise level at all frequencies. Thus objective comparisons were achieved in DP-level. All test subjects were evaluated using the Interacoustics Eclipse device.

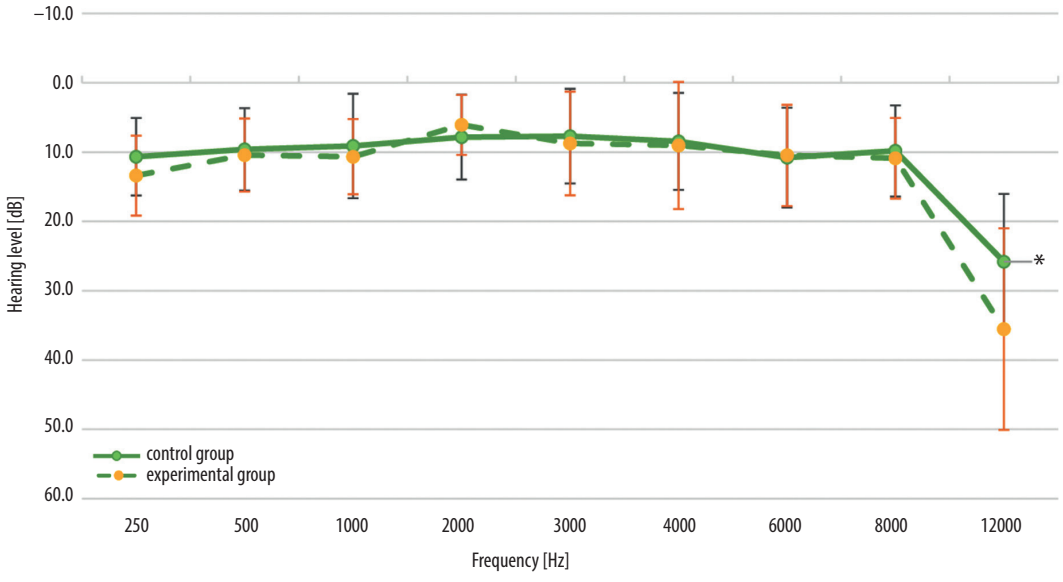

Figure 1. Hearing thresholds for the noise-exposed experimental group and the control group (means and *SD*). Conventional frequencies plus 12 kHz. * = significant difference

- ABR testing at a suprathreshold intensity of 80 dB normal hearing level (nHL) using a click (with pulses of alternating polarity at a rate of 13.1 per second and filtered from 0.1 to 1.5 kHz). This testing assessed the amplitude and latency of ABR waves I and V, as well as the time interval between waves I and V. All test subjects were evaluated by the Interacoustics Eclipse device.

Statistical analysis was done using IBM SPSS Statistics 26. Descriptive statistics, bivariant correlations, and independent samples tests were calculated. Correlations were considered significant at the 0.05 level. For statistical analysis the results for each ear were analyzed separately. In the experimental group $n = 84$ and in the control group $n = 79$.

Results

According to the PTA data in the standard 0.25–8 kHz range, no significant differences were found between the soldier group and the control group. At all frequencies, air conduction thresholds of soldiers and the control group were all under 20 dB HL. However, as shown in **Figure 1**, there was a significant difference between thresholds at 12 kHz ($p < 0.05$). Specifically, the mean PTA result at 12 kHz of the soldiers was 35.5 ± 14.5 dB, whereas that of the control group was 25.8 ± 9.8 dB. As per ISO 7029 standards, hearing at 12 kHz should be less than 20 dB in both our age groups, but in our control group there was still a mild hearing loss at this frequency [15]. The difference between the ISO 7029 data and hearing threshold data for other countries [16] tends to be more pronounced for male adults than for female adults and for higher frequencies than for lower frequencies [16]. The authors consider that the next revision of ISO 7029 will need to be based on data from various countries with uniform ages, frequency ranges, and threshold calculation methods in order to more accurately reflect hearing threshold data.

The discomfort thresholds between the two groups were not significantly different (**Figure 2**). In both groups, the threshold of discomfort was 90 dB HL or greater at all frequencies.

The DP-grams were recorded at frequencies of 1, 2, 4, 6, and 8 kHz. DPOAE testing revealed DP-level differences at some of the tested frequencies between the two groups, but the only significant difference was at 4 kHz ($p = 0.008$). Noise floor levels at all frequencies were not significantly different (**Figure 3**). In the control group there were low values of DP level at high frequencies, and these may be related to the mild hearing loss at 12 kHz, given that DPOAEs are more sensitive for detecting high-frequency hearing loss [17].

Statistical analysis of the ABR results showed significant differences in ABR wave I amplitude and latency between the two groups ($p < 0.0005$ and $p = 0.007$, respectively). The differences in the ABR wave V amplitude and latency were also significant ($p = 0.023$ and 0.044 respectively), but less so than for wave I. Wave I–V interpeak latencies (IPLs) were not different between the two groups ($p = 0.7$).

Discussion

High-level noise exposure can result in some hearing impairment, but the related changes in the hearing system emerge long after the exposure events. However, it is possible to detect these changes at the earlier, nonsymptomic stage with electrophysiological audiological examinations.

Our study showed that the ABR wave I amplitude was lower in the soldiers than in the control group participants, corroborating findings in other studies [1,3]. Studies in animal models with noise-induced and age-related synaptopathies have also shown reductions in the ABR wave I amplitude [18–1]. Such interrelations between the ABR

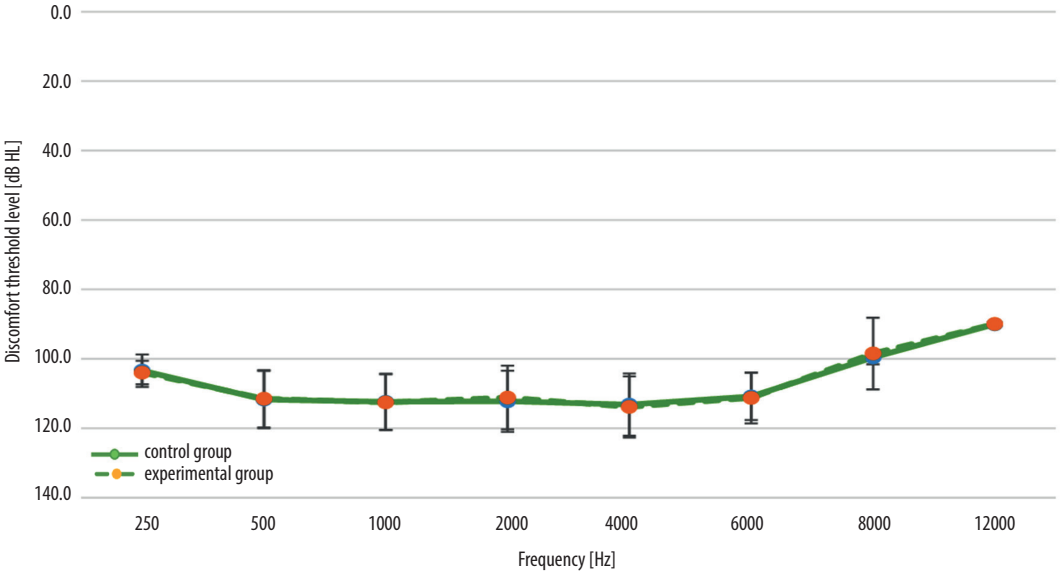

Figure 2. Discomfort thresholds at each frequency for the noise-exposed experimental group and the control group (means and *SD*). Conventional frequencies plus 12 kHz

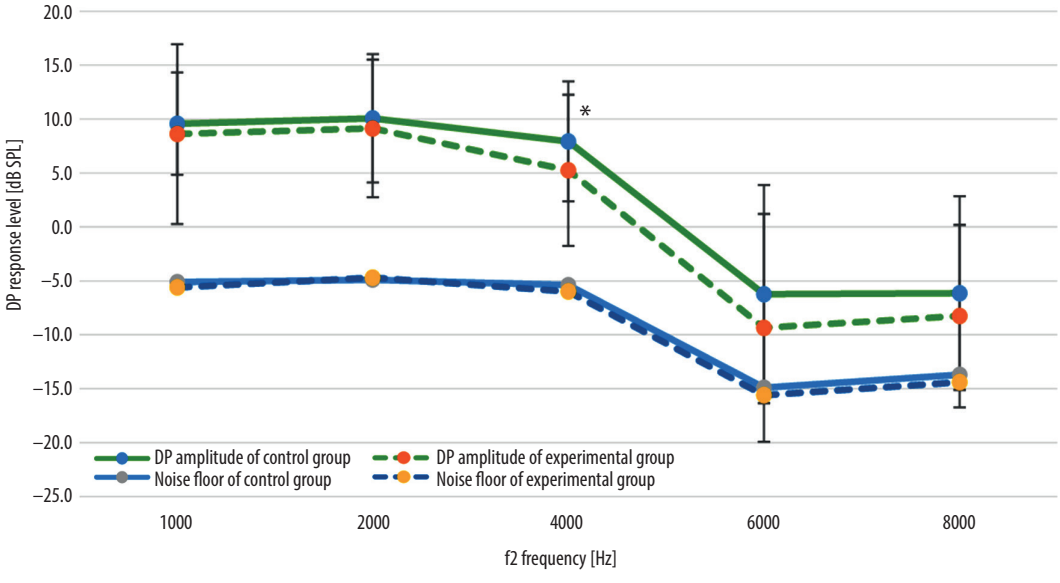

Figure 3. DPOAE amplitude as a function of f2 frequency for the noise-exposed experimental group and the control group (means, *SD*, and average noise floors). * = significant difference

wave I amplitude and synaptopathic processes are also noticeable in humans. Our study could not confirm that a reduced ABR wave I amplitude is conditioned by the synapse loss alone, as we also recorded decreased DPOAE threshold levels at 4 kHz, which reflects outer hair cell damage. Some studies do not support the use of DPOAE assessment as a method for the early detection of noise-induced damage before the behavioural threshold is changed [3]. But a previous study of firearm users revealed significantly lower DPOAEs than predicted from hearing thresholds [22]. Nadon and others demonstrated that the monitoring of an individual's OAEs could be useful in monitoring temporary changes in hearing status induced by exposure to ambient noise [23].

Of course, duration of noise exposure is important too. Trzaskowski and colleagues found that 30-min exposure to amplified music at 87 dBA did not cause measurable PTA threshold shift or significant changes in TEOAE and DPOAE parameters [24]. Another group of researchers demonstrated that a duration of noise from 30 to 60 min changed temporary threshold shifts at several frequencies,

both by conventional and extended high-frequency (EHF) audiometry, but they were minor [25]. Our participants were exposed to loud noise for 44 days.

Research about immediate and long-term impacts of military aircraft noise exposure on noise-induced hearing loss concluded, that EHF is more sensitive in detecting potentially lasting noise-induced hearing loss, whereas DPOAEs are more able to reveal the immediate noise impact on hearing [26].

As per our results there was difference in 10 dB among two groups in 12 kHz frequencies. Similar results have been reported by other authors. Konopka and colleagues showed significant deterioration of hearing, on average by 6 dB, exclusively at frequencies of 10 and 12 kHz after military service [27]. Another group of researchers reported that in adults subjected to steady-state noise mean thresholds from 8–12 kHz were up to 20 dB poorer than in a sample of young normal adults [28]. Some studies do not support the use of EHF audiometry in assessing and monitoring noise-induced hearing loss [29]. In another study similar to ours done on civilian pilots 20–39 years old, a 7.8–9.9 dB decrease in EHF audiometry was reported [30]. Although some authors have documented decreases at standard frequencies in noise exposure groups, it is generally considered that EHF audiometry is more sensitive than conventional audiometry.

Büchler and colleagues believe that PTA remains the most important measurement to monitor acute acoustic trauma, while it may be useful to complement it with EHFA, focusing on the 11–14 kHz range; OAEs are best analysed in the 3–6 kHz range [31]. Based on our results, we come to same conclusion, as we found a significant difference in our groups at 12 kHz, while DPOAE testing revealed a significant difference at 4 kHz.

Our study also confirms an abnormal increase in ABR wave I latencies. A similar result has also been shown by other authors in normal hearing patients with tinnitus. In patients with hearing loss there is an abnormal prolongation of ABR wave I latency, with similar increases in the latencies of later ABR waves [32]. Our study also supports this finding, with a significant hearing threshold reduction at 12 kHz in the high-level noise-exposed patient group relative to the control group. Other authors have stated that, in normal hearing people with tinnitus, prolonged IPLs of ABR waves III–V point to an increased neural conduction time in the upper brainstem, which can be attributed to impaired neural synchronization and transmission in the auditory pathways [33,34]. Our study did not find any evidence of prolonged ABR wave I–V latencies, which suggests that, in high-level noise-exposed individuals with normal hearing, such changes had not yet developed.

According to Kaf and colleagues, noise exposure can result in decreases in the amplitudes of ABR waves I and V [35]. Our study showed such decreases and that the amplitude of wave I had decreased significantly ($p < 0.0005$). In contrast, Suresh and Krishnan saw a smaller ABR wave I amplitude in the noise exposure group than in the low-risk group, alongside similar amplitudes of ABR waves III and V [36]. In contrast to these findings, according to data from Stamper and Johnson [3], the amplitudes of ABR waves I and V were not significantly related to the subjects' NEBs.

We found no significant difference in Loudness Discomfort Level (LDL) between the two groups ($p > 0.05$). Liberman and colleagues found that their high noise exposure group was more likely to report irritation caused by everyday sounds and to avoid noisy environments than did their low noise exposure group [37]. We checked LDL assuming that hyperacusis might be revealed, but it appears that LDL alone is not a good indicator of this condition [38,39].

The significant DPOAE level reduction at 4 kHz, together with the significant reduction in ABR wave I amplitude, in the high noise exposure group may be indicative of simultaneous outer hair cell damage and synaptopathic impairment. Our study confirms the necessity of assessing hearing function in vulnerable patient groups. It appears that the techniques we used may be useful in predicting the development of hearing loss later on.

Conclusion

The results of our study have confirmed that standard audiometric tests are not sufficient to evaluate the effect of gunfire exposure on hearing. Combat soldiers require EHF audiometry, DPOAE testing, and electrophysiological testing. Our findings show the importance of follow-up monitoring of auditory function in noise-exposed individuals. Future studies are needed to determine whether hearing loss develops later in these patients and whether there are ways to prevent this impairment.

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References

1. Bramhall NF, Konrad-Martin D, McMillan GP, Griest SE. Auditory brainstem response altered in humans with noise exposure despite normal outer hair cell function. Ear Hear, 2017; 38(1): e1–e12. https://doi.org/10.1097/AUD.0000000000000370
2. Kujawa SG, Liberman MC. Synaptopathy in the noise-exposed and aging cochlea: primary neural degeneration in acquired sensorineural hearing loss. Hear Res, 2015; 330(Pt B): 191–9. https://doi.org/10.1016/j.heares.2015.02.009
3. Stamper GC, Johnson TA. Auditory function in normal-hearing, noise-exposed human ears. Ear Hear, 2015; 36(2): 172–84. https://doi.org/10.1097/AUD.0000000000000107
4. Attias J, Horovitz G, El-Hatib N, Nageris B. Detection and clinical diagnosis of noise-induced hearing loss by otoacoustic emissions. Noise Health, 2001; 3: 19–31.
5. Lapsley Miller JA, Marshall L, Heller LM, Hughes LM. Low-level otoacoustic emissions may predict susceptibility to noise-induced hearing loss. J Acoust Soc Am, 2006; 120: 280–96. https://doi.org/10.1121/1.2204437

6. Marshall L, Lapsley Miller JA, Heller LM, Wolgemuth KS, Hughes LM, et al. Detecting incipient inner-ear damage from impulse noise with otoacoustic emissions. J Acoust Soc Am, 2009; 125: 995–1013. https://doi.org/10.1121/1.3050304
7. Seixas NS, Neitzel R, Stover B, Sheppard L, Feeney P, Mills D, et al. 10-year prospective study of noise exposure and hearing damage among construction workers. Occup Environ Med, 2012; 69: 643–50. https://doi.org/10.1136/oemed-2011-100578
8. Tepe V, Smalt C, Nelson J, Quatieri T, Pitts K. Hidden hearing injury: the emerging science and military relevance of cochlear synaptopathy. Mil Med, 2017; 182(9): e1785–e1795. https://doi.org/10.7205/milmed-d-17-00025
9. Jedrzejczak WW, Pilka E, Pastucha M, Kochanek K, Skarzynski H. Extended high frequency thresholds and their relationship to distortion product otoacoustic emissions, hearing acuity, age, gender, presence of spontaneous otoacoustic emissions, and side of measurement. Appl Sciences, 2023; 13(18): 10311. https://doi.org/10.3390/app131810311
10. Laffoon SM, Stewart M, Zheng Y, Meinke DK. Conventional audiometry, extended high-frequency audiometry, and DPOAEs in youth recreational firearm users. Int J Audiol, 2019; 58(Suppl. 1): S40–S48. https://doi.org/10.1080/14992027.2018.1536833
11. International Bureau for Audiophonology, BIAP Recommendation 02/1: Audiometric Classification of Hearing Impairments, https://www.biap.org/en/recommandations/recommendations/tc-02-classification/213-rec-02-1-en-audiometric-classification-of-hearing-impairments/file [Accessed 9.07.2024]
12. Jerger J. Clinical experience with impedance audiometry. Arch Otolaryngol, 1970; 92: 311–24.
13. Baraldi Knobel KA, Ganz Sanchez T. [Loudness discomfort level in normal hearing individuals]. Pro Fono, 2006; 18(1): 31–40 [in Portuguese]. https://doi.org/10.1590/S0104-56872006000100005
14. LaGuinn PS, Formby C. Estimates of loudness, loudness discomfort, and the auditory dynamic range: normative estimates, comparison of procedures, and test–retest reliability. J Am Acad Audiol, 2005; 16(2): 85–100. https://doi.org/10.3766/jaaa.16.2.4
15. International Organization for Standardization. Acoustics – Statistical distribution of hearing thresholds related to age and gender. Geneva: International Organization for Standardization; 2017. ISO 7029: 2017; pp. 1–22.
16. Jin I-K, Lee D, Jeong Y, Seo YJ, Kong TH, Suh MJ, et al. Trends in distributions of hearing threshold levels by ages: a comparison of the ISO 7029 and newly available country-specific data. J Audiol Otol, 2024; 28(1): 1–9. https://doi.org/10.7874/jao.2023.00626
17. Lonsbury-Martin BL, McCoy MJ, Whitehead ML, Martin GK. Clinical testing of distortion-product otoacoustic emissions. Ear Hear, 1993; 14(1): 11–22. https://10.1097/00003446-199302000-00003
18. Kujawa SG, Liberman MC. Adding insult to injury: cochlear nerve degeneration after "temporary" noise-induced hearing loss. J Neurosci, 2009; 29: 14077–85. https://doi.org/10.1523/jneurosci.2845-09.2009
19. Lin HW, Furman AC, Kujawa SG, Liberman MCh. Primary neural degeneration in the guinea pig cochlea after reversible noise-induced threshold shift. J Assoc Res Otolaryngol, 2011; 12: 605–16. https://doi.org/10.1007/s10162-011-0277-0
20. Furman AC, Kujawa SG, Liberman MC. Noise-induced cochlear neuropathy is selective for fibers with low spontaneous rates. J Neurophysiol, 2013; 110: 577–86. https://doi.org/10.1152/jn.00164.2013
21. Sergeyenko Y, Lall K, Liberman MC, Kujawa SG. Age-related cochlear synaptopathy: an early-onset contributor to auditory functional decline. J Neurosci, 2013; 33: 13686–94. https://doi.org/10.1523/jneurosci.1783-13.2013
22. Bhatt IS, Lichtenhan J, Tyler R, Goodman S. Influence of tinnitus, lifetime noise exposure, and firearm use on hearing thresholds, distortion product otoacoustic emissions, and their relative metric. J Acoust Soc Am, 2023; 154, 418–32. https://doi.org/10.1121/10.0019880
23. Nadon V, Bockstael A, Botteldooren D, Voix J. Field monitoring of otoacoustic emissions during noise exposure: pilot study in controlled environment. Am J Audiol, 2017; 26(3S): 352–68. https://doi.org/10.1044/2017_AJA-17-0003
24. Trzaskowski B, Jędrzejczak WW, Piłka E, Cieślicka M, Skarzynski H. Otoacoustic emissions before and after listening to music on a personal player. Med Sci Monit, 2014; 20: 1426–31. https://doi.org/10.12659/MSM.890747
25. Kuronen P, Sorri MJ, Pääkkönen R, Muhli A. Temporary threshold shift in military pilots measured using conventional and extended high-frequency audiometry after one flight. Int J Audiol, 2003; 42(1): 29–33. https://doi.org/10.3109/14992020309056082
26. Kuo CY, Hung CL, Chen HC, Shih CP, Lu RH, Chen CW, et al. The immediate and long-term impact of military aircraft noise on hearing: a cross-sectional comparison of fighter pilots and ground staff. Int J Environ Res Public Health, 2021; 18(6): 2982. https://doi.org/10.3390/ijerph18062982
27. Konopka W, Pawlaczyk-Luszczynska M, Sliwinska-Kowalska M, Grzanka A, Zalewski P. Effects of impulse noise on transiently evoked otoacoustic emission in soldiers. Int J Audiol, 2005; 44(1): 3–7. https://doi.org/10.1080/14992020400022561
28. Fausti SA, Erickson DA, Frey RH, Rappaport BZ, Schechter MA. The effects of noise upon human hearing sensitivity from 8000 to 20 000 Hz. J Acoust Soc Am, 1981; 69(5): 1343–47. https://doi.org/10.1121/1.385805
29. Balatsouras DG, Homsioglou E, Danielidis V. Extended high-frequency audiometry in patients with acoustic trauma. Clin Otolaryngol, 2005; 30(3): 249. https://doi.org/10.1111/j.1365-2273.2005.00984.x
30. Ma F, Gong S, Liu S, Hu M, Qin C, Bai Y. Extended high-frequency audiometry (9–20 kHz) in civilian pilots. Aerosp Med Hum Perform, 2018; 89(7): 593–600. https://doi.org/10.3357/AMHP.5029.2018
31. Büchler M, Kompis M, Hotz MA. Extended frequency range hearing thresholds and otoacoustic emissions in acute acoustic trauma. Otol Neurotol, 2012; 33(8): 1315–22. https://doi.org/10.1097/MAO.0b013e318263d598
32. Coats AC, Martin JL. Human auditory nerve action potentials and brain stem evoked responses: effects of audiogram shape and lesion location. Arch Otolaryngol, 1977; 103(10): 605–22. https://doi.org/10.1001/archotol.1977.00780270073012
33. Gabr TA. Auditory brainstem response audiometry in tinnitus patients. Egypt J Ear Nose Throat Allied Sci, 2011; 12(2): 115–20.
34. Schaette R, McAlpine D. Tinnitus with a normal audiogram: physiological evidence for hidden hearing loss and computational model. J Neurosci, 2011; 31(38): 13452–7. https://doi.org/10.1523/jneurosci.2156-11.2011

35. Kaf WA, Turntine M, Jamos A, Smurzynski J. Examining the profile of noise-induced cochlear synaptopathy using iPhone health app data and cochlear and brainstem electrophysiological responses to fast clicks rates. Semin Hear, 2022; 43(3): 197–222. https://doi.org/10.1055/s-0042-1756164
36. Suresh CH, Krishnan A. Search for electrophysiological indices of hidden hearing loss in humans: click auditory brainstem response across sound levels and in background noise. Ear Hear, 2021; 42(1): 53–67. https://doi.org/10.1097/AUD.0000000000000905
37. Liberman MC, Epstein MJ, Cleveland SS, Wang H, Maison SF. Toward a differential diagnosis of hidden hearing loss in humans. PLoS One, 2016; 11(9): e0162726. https://doi.org/10.1371/journal.pone.0162726
38. Sheldrake J, Diehl PU, Schaette R. Audiometric characteristics of hyperacusis patients. Front Neurol, 2015; 6: 105. https://doi.org/10.3389/fneur.2015.00105
39. Zaugg TL, Thielman EJ, Griest S, Henry JA. Subjective reports of trouble tolerating sound in daily life versus loudness discomfort levels. Am J Audiol, 2016; 25: 359–63. https://doi.org/10.1044/2016_AJA-15-0034

Conference reports

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REPORT ON THE 15TH DANUBE SYMPOSIUM OF THE ORL DANUBE SOCIETY, 18–20 APRIL 2024, BUDAPEST, HUNGARY

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The 15th Danube Symposium of the ORL Danube Society took place in Budapest, Hungary, on 18–20 April, 2024. The ORL Danube Society is an association of Danube countries that, among other things, brings together otolaryngologists to exchange knowledge.

The Symposium was divided thematically into 14 sessions, including sessions on cochlear implants, the middle ear, and otoneurology. In the opening session, Prof. Piotr H. Skarzynski gave a presentation entitled *Stapedotomy: tips, tricks and how to avoid potential complications* in which he shared his 40 years of experience in the field of otosurgery at the Institute of Physiology and Pathology of Hearing. His descriptions of how to treat otosclerosis were received with interest and generated a long discussion. He included guidelines on how to safely perform stapedotomy. He recommended the procedure in virtually all forms of otosclerosis, whether in children, adolescents, or adults, and in cases of bilateral or unilateral otosclerosis in the hearing or better hearing ear.

The opening session also included presentations on topics such as *HPV in oncology: what is next?*; *EAS hearing preservation today*; *Hearing reconstruction after surgery for advanced cholesteatoma of the middle ear*, and *Complications after thyroidectomy*.

Other sessions at the conference on topics such as oncology and otoneurology, and a session devoted entirely to the larynx, were also very well-attended.

The session on cochlear implants provoked the most discussion. It included the following presentations: *Hearing solutions for patients with Treacher Collins Syndrome (TCS); Hearing rehabilitation with a CI in postmeningitis deafness; How to consider indications for cochlear implantation in cases where there are discrepancies between subjective and objective audiological measurements; Early hearing rehabilitation with cochlear implantation after pneumococcal meningitis: a case report; Cochlear implantation with the "pull-back" electrode insertion technique controlled by Transimpedance Matrix (TIM); and Cochlear nerve diameter may influence audiological progress in CI users.*

Prof. Piotr H. Skarzynski giving his presentation at the opening session

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REPORT OF THE 8TH INTERNATIONAL SYMPOSIUM ON MENIERE'S DISEASE AND INNER EAR DISORDERS, 25–28 APRIL 2024, SHANGHAI, CHINA

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The 8th International Symposium on Meniere's Disease and Inner Ear Disorders was held in Shanghai from 25 to 28 April 2024. The last such event was held in Italy in 2015. The Shanghai symposium was scheduled for 2020, but unfortunately, due to the COVID-19 pandemic, the congress was postponed until this year so that we could finally meet face to face.

For more than 40 years, the International Symposium on Meniere's Disease and Inner Ear Disorders has brought together specialists from around the world to share experiences and establish collaborations in the field of neurotology. The program of this year's meeting focused on the latest research on Meniere's disease and innovative techniques for its treatment. The Institute of Physiology and Pathology of Hearing was represented by Aleksandra Kolodziejak, MSc.

At the opening ceremony Professor Jun Yang welcomed us and gave a brief history of Shanghai. Later, he presented a consensus on the administration of oligodynamic drugs for treating Meniere's disease. He highlighted the advantages and disadvantages of administering gentamicin, glucocorticosteroids, and other drugs. On the first day, Dr Yiali Shu presented an interesting paper on AAV-hOTOF gene therapy in children with autosomal recessive deafness 9 (DFNB9), describing some impressive results. After just 6 weeks, his little patients started to respond to their names and after 3 months some of them started to say their first words.

On the second day, Professor Yang presented the results of a pilot study demonstrating the importance of screening vestibular function in neonates and young children referred for cochlear implantation. Dr Daniel Brown presented the results of preliminary work on a fully implantable biosensor for patients with Meniere's disease, although at present testing is in the early stage in guinea pigs. His presentation generated considerable interest and there was a lengthy discussion among the audience.

In the poster session, Aleksandra Kolodziejak presented the results of her work on "Vestibular preservation after cochlear implantation in partial deafness treatment", co-authored by Dr Magdalena Sosna-Duranowska, Prof. Piotr Skarżyński, Dr Grażyna Tacikowska, Dr Elżbieta Gos, Ewa Tomanek, and Prof. Henryk Skarżyński.

Conference participants were able to attend workshops held by various companies. Various methods of testing the vestibular organ were demonstrated, one of which included the possibility of using standard audiological equipment (an impedance bridge and an audiometer) to diagnose patients with Meniere's disease.

The Symposium was a unique event that provided opportunities for gaining new knowledge, exchanging experiences, and presenting results and achievements in the field. The event provided an opportunity to learn about new research directions and the needs of patients.

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World Hearing Center

OF THE INSTITUTE OF PHYSIOLOGY AND PATHOLOGY OF HEARING

The World Hearing Center is a modern specialized hospital providing medical care at the highest quality level in the fields of otolaryngology, audiology, phoniatrics, rehabilitation and biomedical engineering. It is superbly equipped for research and education, and includes modern conference facilities. The Center conducts a wide range of research and educational activities addressed to specialists from Poland and other countries. The Center is one of the leading medical institutions in the field of hearing disorders treatment, running, among others, one of the largest hearing implant programs in the world and performing 15,000 to 21,000 surgical procedures yearly.

The Center provides its patients with comprehensive diagnostics, conservative treatments, and surgery for the rehabilitation of:

- congenital and acquired malformations of the external, middle and inner ear,
- hearing, speech and balance disorders of different etiologies,
- disorders of the mouth cavity, throat and larynx,
- disorders of the nose and paranasal sinuses,
- sleep disorders.

World Hearing Center:

- is a global leader in terms of the number of performed otorhinolaryngological surgeries and the number of outpatient consultations (more than 200,000 consultations per year),
- is the place where unique and highly specialized medical procedures are performed, including reconstruction surgeries of congenital defects of the outer ear, treatment of profound and partial deafness with various hearing implants, phonosurgeries, endoscopic sinus surgeries under image guidance, and many others,
- employs a team of highly qualified and experienced specialists,
- has state-of-the-art medical equipment and instrumentation,
- offers comfortable conditions for hospital stays,
- uses the most modern telemedical solutions providing remote consultations via the world-first National Network of Teleaudiology.

The team of the Institute of Physiology and Pathology of Hearing and its individual employees are winners of numerous international and national awards.

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