Compendium
Active echolocation for people with visual impairment

The publication elaboration leader:

Fundacja Instytut Rozwoju Regionalnego

This publication is elaborated within the project “Echolocation for People with visual impairment” with the support of Erasmus+ programme of European Union.

Partner organizations participating in the project:

Fundacja Instytut Rozwoju Regionalnego, leader, Poland

Instituttet for Blinde og Svagsynede, Denmark

Kommunikationscentret, Region Hovedstaden, Denmark

Kauno Prano Daunio ugdymo centras, Lithuania

Krakow 2019

Edited by Fundacja Instytut Rozwoju Regionalnego on Creative Commons Licence

"The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.”

CONTENTS

Active echolocation for people with visual impairment 1

PREFACE....5

INTRODUCTION....6

SHORT HISTORY OF ECHOLOCATION....**Błąd! Nie zdefiniowano zakładki.**

The development of echolocation....8

Famous echolocators inspiring others and teaching echolocation....9

REVIEW OF RECENT RESEARCH/ECHOLOCATION STUDIES....13

The first research on echolocation: bats research....14

The first research on echolocation: human research....14

Pioneer research on echolocation....15

Studies comparing the echolocation ability of blind and sighted people....15

Research on echolocation: acoustic properties of the echo and the environment..16

Research on echolocation: echolocation abilities of blind and sighted people....18

Research on echolocation: the neuroimaging method....19

BASIC INFORMATION ABOUT ECHOLOCATION....20

Theory of echo sounds and their properties....21

Definitions of echolocation....24

Types of echolocation: active and passive echolocation echolocation....26

Types of echolocation and their effectiveness....29

THE APPLICATION OF ECHOLOCATION IN EVERYDAY SITUATIONS/PRACTICE....31

The environment where visually impaired people use echolocation....31

Description of the exemplary situations of the use of echolocation....33

Factors affecting the use of echolocation by visually impaired people....35

TEACHING ECHOLOCATION 37

Stages of teaching echolocation.. 37

Case studies... 38

REFERENCES 45

Books 45

Articles 46

Websites and other materials... 51

PREFACE

The main aim of this publication is to gather the most important information about human echolocation, especially echolocation of people with visual impairment. The collected knowledge is basic and reliable material giving a strong fundament

for the professional area. This compendium is an introduction to the concepts of echolocation. It will provide you with the fundamental understanding of echolocation (theoretical background) and how echolocation is used now, as well as how it can be practised and refined by anyone willing to learn.

The publication consists of the introduction and five basic chapters. The introduction presents the most important conceptual assumptions of the “freedom formula and self-directed discovery” developed by Daniel Kish.

The first chapter is the historical background for the development of echolocation. It contains the most important information on the discovery of echolocation and presents the profiles of selected people who teach echolocation (James Holman, Ben Underwood, Daniel Kish).

The second chapter focuses on research on echolocation in the world. This chapter presents an overview of the most important studies on the echolocation of people with visual impairment.

The third chapter contains basic information about echolocation. This chapter presents the theory of sounds and their properties. This part of the publication states an issue of defining echolocation and describes the types of echolocation.

The last chapters of the compendium are devoted to practical issues related to teaching echolocation to people with visual disabilities. The fourth chapter contains descriptions of using echolocation in everyday life.

The fifth chapter focuses on the general rules and strategies of echolocation teaching. This chapter contains tips
on developing echolocation skills among people with visual impairment (children, adults) and people with additional disabilities (mental disabilities, deaf-blind, etc.).

The last part of the compendium is a list of literature (books and articles) and list of websites and other materials about echolocation.

The compendium contains basic knowledge about echolocation of people with visual impairment. The collected knowledge and practical issues can be useful for all professionals working with people with visual impairment, in particular for teachers, orientation and mobility instructors, occupational therapists, students. This publication is also addressed to people with visual problems interested in the subject of echolocation.

This publication is the outcome of international cooperation under the framework of Project No. 2017-1-PL01-KA204-038557: “Echolocation for people with visual impairment”, implemented as part of the ERASMUS + Program, Action 2 Strategic Partnerships.

INTRODUCTION

Introduction to echolocation

Bats and dolphins are known for their ability to use echolocation. They emit bursts of sounds and listen to the echoes that bounce back to detect the objects in their environment. What is not as well-known is that some blind people have learned to do the same thing, making mouth clicks, for example, and using the returning echoes from those clicks to sense obstacles and objects of interest in their surroundings.

The skill of echolocation is not available only to people with special talents and those who have an extremely developed sense of hearing. This ability is possessed by man regardless of whether he/she is blind or seeing. However, in the case of blind people, this ability is of particular importance for orientation in the environment.

Echolocation may enable some blind people to do things that are otherwise thought to be impossible without vision, potentially providing them with a high degree of independence in their daily lives and demonstrating that echolocation can serve as an effective mobility strategy among the blind.

The freedom formula and self-directed discovery by Daniel Kish

Daniel Kish has developed a way of thinking about the development and learning which he calls **“Freedom formula”** (Kish, 2014). It is a key issue in Daniel Kish’ approach, whereby he focuses on possibilities rather than limitations in his echolocation training. The freedom formula is a way of thinking on how to travel independently by learning **”self-directed discovery”** and by using the flash sonar in orientation training in combination with the cane.

Self-discovery means motivation and responsibility for your own travel. In order for this independent discovery to be possible, a blind person must be able to move freely (unrestricted by the fears of other people) and take initiatives to discover the world through self-discovery (Kish, 2016). Independence allows a blind person to learn to perceive the world in their own way and to personally experience the world and to personally take the initiative to do so. Inner curiosity and the need to explore the world (getting useful information about the environment) will be the best motivation for independent movement.

The factors influencing learning and development boil down to three main conditions:

- motivation (preferably intrinsic motivation under positive circumstances);
- regular practice and application;
- increasingly challenging activities or circumstances.

Above all, it is ideal for the student to have and apply a positive and hopeful attitude about his/her own capabilities.

In this view it is not about trying to teach a learner the teacher’s knowledge but fostering a student’s ability to learn. The role of the teacher is to support the process;

he/she does not make the process. The teacher's role is "not to teach blindness skills per se, but to teach the student how to learn blindness skills independently".

The Freedom formula includes the following key practical elements:

- provision of developmental information (human development) and introduction to brain development (the nervous system);
- reduction of external controls over the student/learner;
- reduction of tactile dependency on physical surfaces (walls, furniture, and so on);
- introduction of a new form of cane training: perception cane training;
- systems re-integration into family and community dynamics;
- active echolocation training: the flash sonar

The components run parallelly to each other and are integrated. They are not steps – rather an interactive and dynamic system of perception and action. Humans do not learn best by sequenced instruction, but by relevance – referring back to need, importance meaningfulness to the individual (Kish, 2016, p.192).

The development of echolocation

Like our fellow mammals, dolphins and bats, humans can find their way through the environment by making sounds and listening for the echoes. With practice, we can learn to use the volume, pitch and timbre of echoes from a tapping cane, or one's own voice, to navigate through the environment without relying on sight.

The term 'echolocation' was first used by **Donald Griffin in 1944** to describe the outstanding ability of bats flying in the dark to navigate and to locate prey using sound. Echolocation has since been identified and extensively studied for other animals, including dolphins and toothed whales.

In **1749, Diderot** described a blind acquaintance who was able to locate silent objects and estimate their distance, although at that time it was not known that sound was involved. Diderot believed that the proximity of objects caused pressure changes on the skin, and this led to the concept of 'facial vision': objects were said to be felt on the face.

As early as in the **1940s** a series of experiments was performed in the **Cornell Psychological Laborator**y, showing that sound and hearing, rather than pressure changes on the skin, were the mechanisms driving this ability.

Famous echolocators inspiring others and teaching echolocation

Echolocation is a skill that still requires research and learning the best way to teach it. In the world there are some blind individuals who have developed remarkable echolocation skills and are able to assess the position, size, distance, shape, and material of objects using reflected sound waves. These blind people taught themselves how to use echolocation "by trial and error".
Currently the best-known cases of these are: an American, Daniel Kish, the only blind person to have been awarded a certificate to act as an orientation and mobility instructor for other blind people, and Ben Underwood, who was considered to be the world's best "echolocator" until he died at the start of 2009.

Source: Wikipedia

- known as the 'Blind Traveller';

- a Fellow of the Royal Society of London for Improving Natural Knowledge, commonly known as the Royal Society;
- a British adventurer, author, and social observer, best known for his extensive travelling and the writings he compiled to document them;
- at the age 25 he was invalided by an illness that first afflicted his joints, then finally his vision;
- he was studying medicine and literature at the University of Edinburgh;
- despite the fact that he was blind, he undertook a series of solo journeys that were unprecedented both in their scope and the fact that he undertook them using echolocation
- in 1832, Holman became the first blind person to circumnavigate the globe;
- by October 1846 he had visited every inhabited continent;
- he lived in a time when blind people were thought to be almost totally helpless, and usually given a bowl to beg with, Holman's ability to sense his surroundings by the reverberations of a tapped cane or horse's hoof-beats was unfathomable.

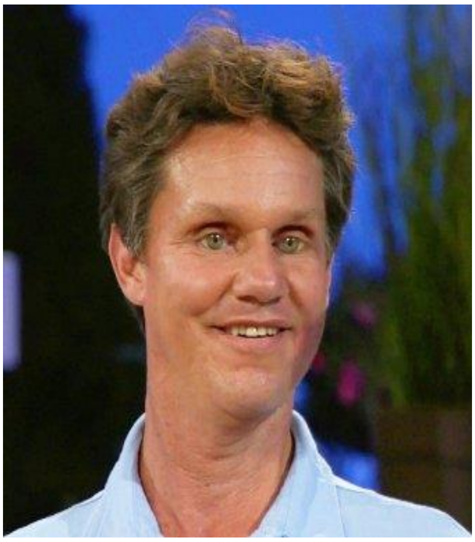
Ben Underwood (26 January 1992 - 19 January 2009)

Source: Wikipedia

- known as ‘the boy who saw without eyes’;

- when he was two, he was diagnosed with retinal cancer and a year later had to get his eyes removed;
- at the age of five he started learning echolocation on his own;
- by making clicking noises with his tongue and listening to the sound waves he created he learned to identify objects and get around safely;
- he engaged in all of the normal activities of childhood and youth: he played basketball, danced, practised karate, skated and rode a bike through his neighborhood, rollerblading, playing football, and skateboarding, mastered video games by memorizing scenarios and identifying sounds that characters made just before they changed positions;
- died at the age of 16, from the same cancer that took his vision;
- he was the inspiration for Andrzej Jakimowski, a Polish Film director, who made a film titled “Imagine” in 2012 about the life of an echolocation instructor to work with visually challenged.

Daniel Kish (1966 -)



Source: twitter Daniel Kish

- known as ‘Batman’;
- he is an American expert in human echolocation and the President of the World Access for the Blind (WAFTB);

- the world’s first totally blind person to receive orientation and mobility certification to teach blind people how to navigate: Certified Orientation and Mobility Specialist (COMS) and The National Blindness Professional Certification (NOMC);
- he holds master's degrees in developmental psychology and special education from University of California Riverside;
- he lost his sight as a baby when he was diagnosed with retinal cancer (he had his eyes removed at the age of 13 months);
- he learned to make palatal clicks with his tongue when he was still a child;
- he developed a technique using his white cane combined with echolocation to further expand his mobility;
- he is able to distinguish a metal fence from a wooden one by the information returned by the echoes on the arrangement of the fence structures;
- he and his organization have taught a form of echolocation to at least 500 blind persons around the world;
- he lives an active life: travels, rides a bike, climbs the mountains.

The World Access for the Blind (WAFTB)

California-registered nonprofit organization founded by Daniel Kish in 2000 to facilitate "the self-directed achievement of people with all forms of blindness" and increase public awareness about their strengths and capabilities.

The primary work of the non-profit is to encourage and teach blind people the technique of echolocation for their movement, so as to minimize their inhibition with respect to people with normal sight. Their innovative training is called Flash Sonar, which involves using sound for navigation. Their strategic campaigns are based on the philosophical stand: No Limits. As the President of the World Access for the Blind, one of Kish's missions is helping blind people learn to cook, travel, hike, run errands, and otherwise live their lives more independently—with sound.

Tim Johnson

Source: twitter Tim Johnson

- children's books author;
- entrepreneur;
- engineer;
- the author of the book entitled *Beginner's Guide to Echolocation for the Blind and Visually Impaired: Learning to See with Your Ears*;
- *The Beginner's Guide to Echolocation* has been reviewed and adopted by vision organizations around the world to help aid their mobility training programs;
- martial arts instructor; he works with young children as well as adults to help them understand their true potential;
- he founded the Martial Arts Lineage Project in 2010 to help bring the worldwide community of martial artists closer together;
- he is passionate about life and helping all people realize their dreams and accomplish their most ambitious goals.

REVIEW OF RECENT RESEARCH/ECHOLOCATION STUDIES

Echolocation issues among visually impaired people have been and still are of interest to various groups of scientists. Research on echolocation was usually embedded in the field of acoustics, cognitive psychology, psychoacoustics. The development of neuroscience (explaining the cognitive functioning of man based on the functioning of the brain) has made this area an interest of scientists in the field of neuropsychology and information engineering.

The first research on echolocation: bats research

The phenomenon of echolocation or the use of sounds reflected from an obstacle to orientation in the surroundings was observed in bats.

- **1793: Lazzaro Spallanzani** conducted observations of bats and discovered that they use reflected sound for orientation in the environment;
- **1794: Charles Jurines** discovered that if bats have plugged ears, they are unable to use the ability of echolocation and, when flying, collide with an obstacle;
- **1944: Donald Griffin** showed that bats use the sound they produce to navigate and locate victims using sounds (Wiener, Lausen, 1997, p. 146).

The first research on echolocation: human research

Parallel to observations and discoveries of zoologists, the first reports on the use of echolocation skills in humans were recorded.

- **1749: Denis Diderot** described the case of a blind man who located various objects and was able to estimate their distance. Diderot explained this skill as feeling the closeness of objects in the surroundings and called this ability 'seeing face' (Koralik, Cirstea, Pardhan, Moore, 2014, p. 63).
- **1872–1918:** different researchers (Levy, 1872, James, 1890, Dressler, 1893, Heller, 1904, Javal, 1905, Villey, 1918, etc.), sought to clarify the ability to locate objects by the blind, they called it 'face seeing', 'sixth sense', 'the sense of obstacles'. Researchers formulated a number of theories explaining the mechanism of action of the sense of obstacles: Truschel's acoustic theory,

Kunz's compression technique, Krogius' thermal acoustics, Villey's auditory, complex reception of Heller's impressions (Wiener, Lausen, 1997, p.146).

- **1930: Włodzimierz Dolański** conducted experiments with blind people. He checked the detection of the shield close to the exposed face, using earmuffs, using a mask and with cotton wool in the ears. Experiments showed that the basis of the sense of obstacles is hearing (Dolański, 1954, pp. 36–41).

Pioneer research on echolocation

- **1940:** pioneering research carried out at the Cornell Psychological Laboratory by **Karl M. Dallenbach** (professor at Cornell University), Michael Supa (blind echolocator), **Wilton Cotzin** (seeing echolocator).
- Two sighted and two blind people took part in the study. The subjects were asked to approach an obstacle and report the fact as soon as they were able to detect it and then stop as close as possible to the obstacle. When the participants of the study covered their ears (headphones with loud music were put on) they could not detect the obstacle.
- As a result of the research, it was found that face-seeing is auditory and not tactile, and that acoustic stimulation is necessary to detect and locate objects in the environment (Supa, Cotzin, Dallenbach, 1944, pp. 133–183).

Studies comparing the echolocation ability of blind and sighted people

- **1960: Charle E. Rice** carried out research involving blind people (5 blind people from birth, 3 blind people after 3 years of age) and sighted people. As a result of the research, it was established that both blind and sighted people are able to echolocate at a comparable level (Kuczyńska-Kwapisz, Śmiechowska-Petrovskij, 2017, p. 43).

- **1962: Kellogg** determined that blind people have a better ability to detect reflected sound (echoes) than sighted people, and that 'obstacle detection' is better for blind people from birth than for the blind or visually impaired.

Research on echolocation: acoustic properties of the echo and the environment

- **1980: Bo. N. Schenkman** analyzed the influence of several factors (sound sources, physical object parameters and type of tasks) on the abilities of blind people and examined the psychoacoustic mechanisms of echolocation.
  As a result of the research, it was found that the detection of objects in the environment based on the sounds produced by the white cane (in contact with the ground) is more difficult for the blind echolocators than the language wiping. It was found that the length of the sound signal emitted has an impact on the effective detection of objects in the environment; short signals are better in the location of objects, and continuous signals are better for determining the physical characteristics of objects (Arias, Bermejo, Hüg, Venturelli, Rabinovich, Skarp, 2012, p. 22).
- **1990: Claudia Arias and O.A. Ramos** investigated the effect of pitch heights in detecting objects in space. They used both language clicking and sound emitted from the loudspeaker (independent or with an echo) to carry out the study. The tasks used in the study included detecting various objects (distinguishing sounds from and without echoes) and distinguishing between changing the distance between the sound source and the object. As a result of the conducted research, it was determined that the pitch of sound is important for faster location and detection of objects in space and for distinguishing their distances (Arias, Ramos, 1997, pp. 399–419).
- **2000: Lowrence D. Rosenblum** investigated the effect of motion on echolocation skills. As a result of the research it was established that blind people who used echolocation during movement achieved better results

in detecting obstacles than those using echolocation stationary. (Kolarik, Cirstea, Pardhan, Moore, 2014, pp. 60–68).

- **2007: Juan A. M. Rojas** and others conducted research on the properties of the most common impulses generated during echolocation. During the tests it was checked which sounds produced by humans for echolocation are the most effective. Clapping in the hands, clicking with fingers, clapping castanets and tongue-clicking were analyzed. As a result of the research it was found that the best sound for echolocation is the so-called tongue-wrenching. It consists in "a sharp, horizontal withdrawal of the tongue towards the back of the mouth, previously pinned to the palate, above the upper teeth, with slightly parted lips". Very important is also the tactile touch of the tongue, which is felt as a vibration on the tongue, teeth, jaws and bones of the skull. This type of hitting is very effective in detecting and locating obstacles located at the level of the head of an echolocator and when detecting very small objects in space. (Rojas, Hermosilla, Montero, Espí, 2010, p.1073).
- **2010: Bo Schenkmen and Mats E. Nilsson** tried to determine what components of the acoustic stimulus affect echolocation. They carried out research consisting in pointing blind and sighted people (ten blind and ten sighted people aged between 30 and 60), which of the two sounds presented is the sound reflected from the obstacle. The presented sounds differed in the volume and pitch parameters. As a result of the research, it was established that a person with visual disability who is in close proximity to the object for echolocation, usually uses the pitch of sound, while the sound volume is an additional source of information for him or her. Researchers also found that the size of the room affects the distance from which echolocation can be used. In large rooms, for example a conference room, this distance may be larger than in very small rooms, e.g. in an anechoic room. Blind people in this experiment achieved better results than sighted people (Schenkmen, Nilsson, 2010, p. 485).
- **2016: Bo N. Schenkmen** conducted a study to check the impact of the amount of acoustic information on echolocation abilities in blind people. As a result of the conducted research, it was established that for the blind the presence of a large

amount of acoustic information makes perceptual tasks (e.g. detection of an obstacle) easier than when there is little information. The study confirmed the benefits of the 'excess information' principle in echolocation (Schenkmen, 2017, p. 3452).

- **2017: Liam J. Norman, Lowrence D. Rosenblum, Lore Thaler** studied the best acoustic characteristics of blind people. They carried out research in a group of 12 blind people (8 women and 4 men aged 18 to 41), assessing the presence of the object in the environment and the distance of the object based on echo recordings at different frequencies. As a result of the conducted research, it was established that blind people producing clicks containing higher spectral frequencies found and located objects in the environment much better than blind people using clicks with lower frequencies. Sound emissions containing higher spectral frequencies produced louder echoes that were better audible (Norman, Thaler, 2018, p. 16).

Research on echolocation: echolocation abilities of blind and sighted people

Researchers dealing with echolocation outside the acoustic sphere of echolocation were also interested in the impact of the time of vision loss on the skill of echolocation and the ability to control it by sighted people.

- **2010: Santani Teng, David Whitney** conducted research to check the skills of echolocation in blind people (with different experience in using echolocation) and seers. The results of the conducted research showed that the best and most precise echolocation was shown by people who had experience in the use of echolocation and people who lost their sight in their early childhood. Therefore, the time of the loss of vision and echolocation experience are important for the presented skills of echolocation (the study showed a strong correlation between the age of blindness and the ability to echolocalize, consistent improvement of results obtained through practice) (Theng, Whitney, 2011, 20–32).

- **2012: Andrew J. Koralik** and others conducted a study comparing the performance of echolocation in the sighted and blind. Studies showed that blind people show a higher sensitivity to non-generated information from sounds reflected from an obstacle than sighted people (e.g. sounds emitted from a loudspeaker) and are better able than sighted to perform the task of distance discrimination when there were available only signals from the echo. In both groups, large individual differences in echolocation skills were also observed (Norman, Thaler, 2018, pp. 1–18).
- **2017: Michał Bujacz** and others compared the skills of echolocation (detecting obstacles from different distances) in the natural environment in the group of blind children, blind adults and adult sighted people. They also compared the accuracy of recognizing the same scenes using binaural recordings and a mobile application. The obtained research results will be used to create several mobile applications supporting the development of echolocation. Each of the designed applications will be devoted to a different issue. The first will be a tool for learning to distinguish sounds at the basic level. The second one will help in learning passive and active echolocation (at various levels of advancement) for people with visual disabilities and also as a support for teachers of spatial orientation. The third application will be an audio game in which the echolocation will be used (Bujacz, 2018).

Research on echolocation: the neuroimaging method

In recent years, extremely interesting studies using the neuroimaging method have appeared among the studies on echolocation. Two independent teams of scientists (a team of American psychologists from the University of Western Ontario in Canada and a team from the University of California) have observed cerebral activity of blind people who, on the basis of the reflected echo, were able to assess the properties of objects (metal, fabric, wood, etc.). In both studies, cortical activity of the brain was also observed in areas typical of visual perception (Goodle, 2013, p. 45).

- **Malvyn Goodale:** professor of psychology, director of the Brain and Mind Institute at the University of Western Ontario in Canada, conducted research using functional magnetic resonance imaging (fRMI). Together with the team, he was involved in the study of functional organization of visual pathways in the cerebral cortex. As a result of the experiments conducted with Daniel Kish and Brian Bushway (blind men using echolocation to move), he discovered that only in them, when hearing reflected sounds, the visual cortex activates in the brain. However, only the auditory cortex is activated in sighted persons subjected to the same effects. Professor Goodale determined that echolocation can be used in a very similar way to eyesight (Goodle, 2013, p. 44).
- The discovery of 'brain plasticity' made during the research has enormous significance for blind people (echolocation can be used in a similar way to eyesight) but also allows better understanding of brain activity in sighted people.

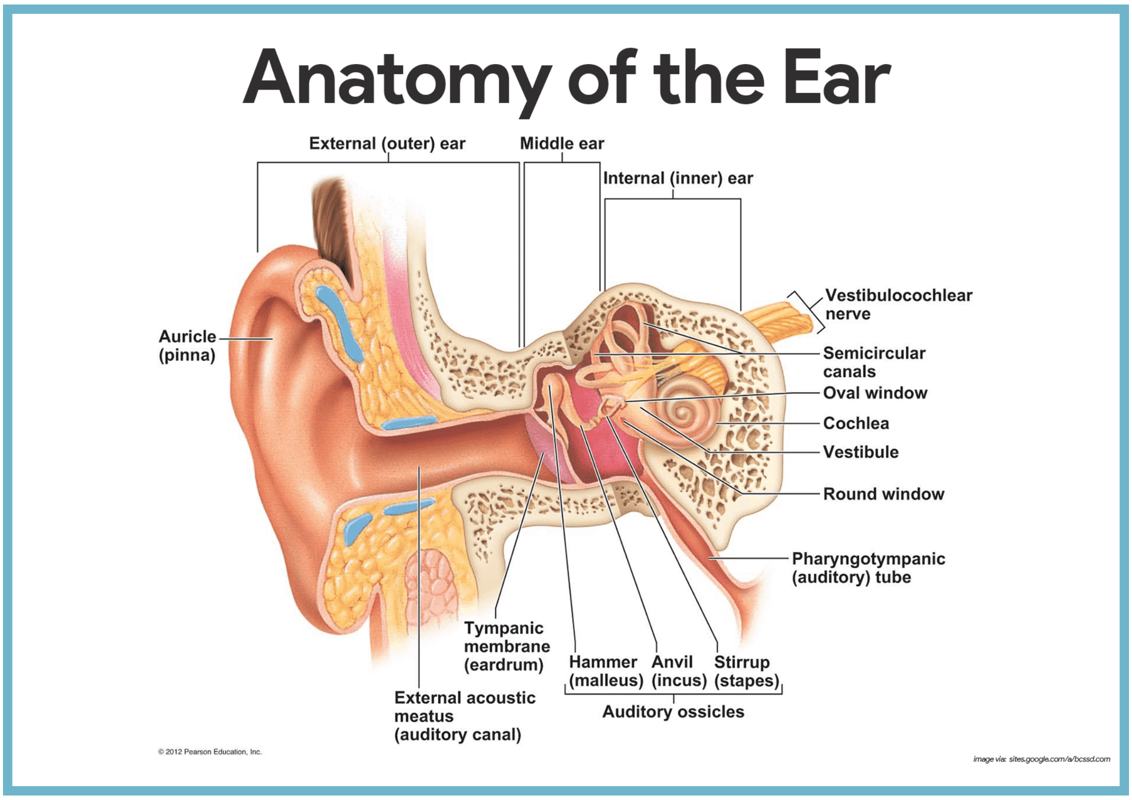
In recent years, there has been a great interest in the echolocation skills of blind people. It translates into research interests of scientists around the world. However, the biggest limitation of the conducted research are not many research samples (from several to a dozen people or so), which means that the research results cannot be extended to the entire population of people with visual disabilities. In spite of this, the conducted research allowed the determination of the mechanism of echolocation, factors that determine its effectiveness, acoustic mechanisms and its neurological foundations.

BASIC INFORMATION ABOUT ECHOLOCATION

People with visual impairment in the process of spatial orientation use information obtained from other senses: hearing, touch, kinesthetic sense, sense of balance, sense of obstacles and smell. The main role in the process of orientation in the space in people with sight dysfunction is hearing. It is the first sense that provides information about the existence of objects in the space (e.g. obstacles along the route) and helps determine if the object being heard is static or dynamic (e.g. a bus standing at the bus stop, a bus leaving the bus stop).

Theory of echo sounds and their properties

Sound is very important in human life. It allows you to communicate with the world around us and other people. It helps in learning communication through speech development. In the case of blind and visually impaired people, it also plays a significant role in learning about the space and getting to know it.
Sound: physics. a wave disorder in a gaseous, liquid or solid elastic medium (elastic waves) that produce a subjective auditory impression in a human or animal. Three important characteristics of sound are intensity, frequency, and phase. These characteristics contribute to sound identification, discrimination, and location.



Source: www.[nurseslabs.com/special-senses-anatomy-physiology](http://www.nurseslabs.com/special-senses-anatomy-physiology)

Anatomically, the ear is divided into three major areas: the outer ear, the middle ear and the inner ear. The outer ear consists of the pinna and ear canal. It collects and conducts airborne sound waves to the eardrum in the middle ear. Dysfunction in the outer ear results in conductive hearing loss. The middle ear consists of the eardrum and three ossicles. The middle ear changes the airborne sound transmitted from the outer ear into a mechanical vibration that is passed on to the inner ear through the motion of the ossicles. Dysfunction in the middle ear results in conductive hearing loss. The inner ear consists of the Cochlea. The primary functions of the inner ear are to transform mechanical energy into electrochemical energy and to perform a frequency analysis of the incoming signal. Dysfunction in the inner ear results in sensorineural hearing loss.

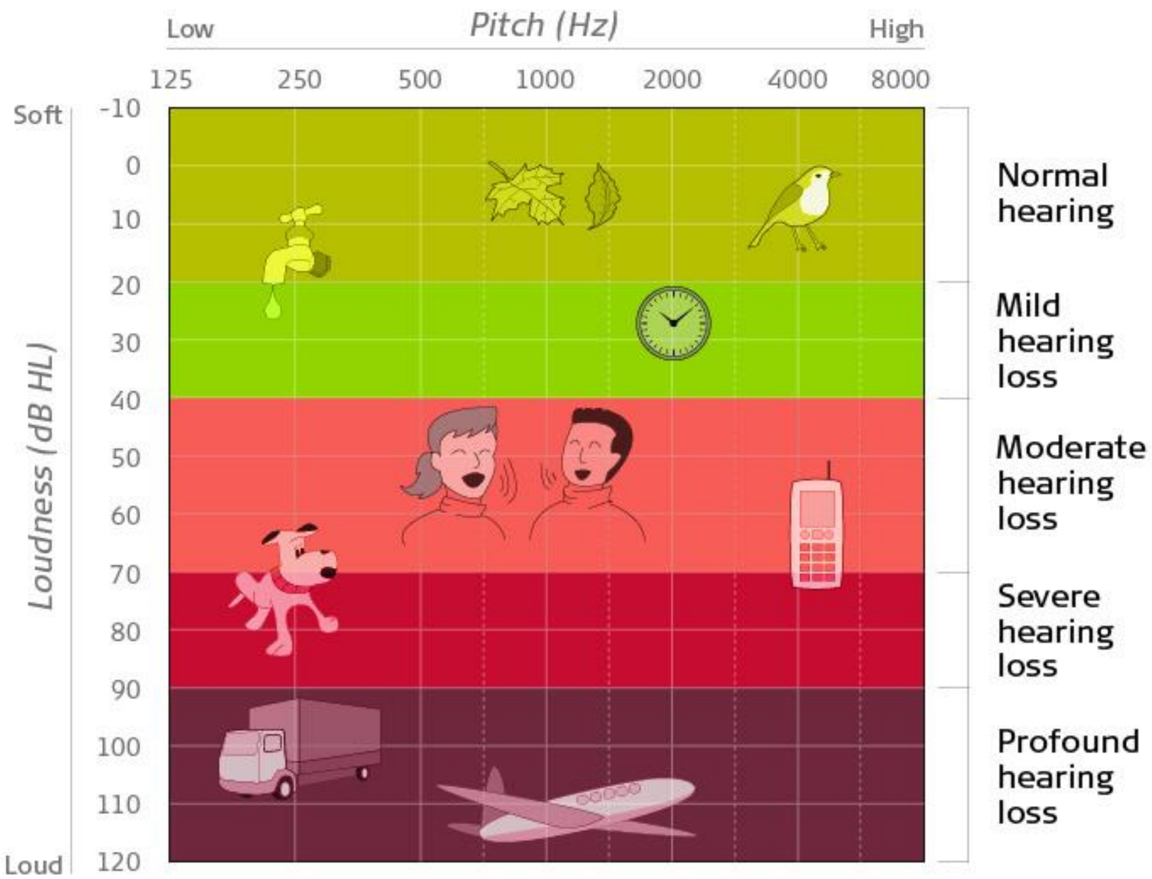
Source: www.visual.ly/community/infographic/health/types-hearing-loss

Conductive hearing loss occurs when there is a problem with the outer or middle ear which interferes with the passing sound to the inner ear. It can be caused by such things as too much earwax, ear infections, a punctured eardrum, a fluid build-up, or abnormal bone growth in the middle ear such as otosclerosis. It is more common in children. Individuals with conductive hearing loss usually have losses in the lower frequencies or have a more or less equal loss across the frequencies.
Sensorineural hearing loss occurs when the hearing organ, the Cochlea, and/or the auditory nerve is damaged or malfunctions, so it is unable to accurately send the electrical information to the brain. Sensorineural hearing loss is almost always

permanent. It can be genetic or caused by the natural ageing process, diseases, accidents or exposure to loud noises and certain kinds of chemicals and medications. Auditory neuropathy is another form where the nerves that carry sound information to the brain are damaged or malfunction. Technologies such as Hearing Aids, Cochlear Implants and Hybrid Cochlear Implants can help reduce the effects of having sensorineural hearing loss.

People with sensorineural loss usually have loss in the upper frequencies.

A mixed hearing loss occurs when both conductive hearing loss and sensorineural hearing loss are present. The sensorineural component is permanent, while the conductive component can either be permanent or temporary.



Source: www.medel.com/pl/audiogram

The audiogram is a ‘graphic representation’ of the auditory possibilities. This graph indicates how large is the deviation of the patient's hearing from the normal level, and in the case of hearing loss makes it easier to locate the problem. There are different types and degrees of hearing loss.

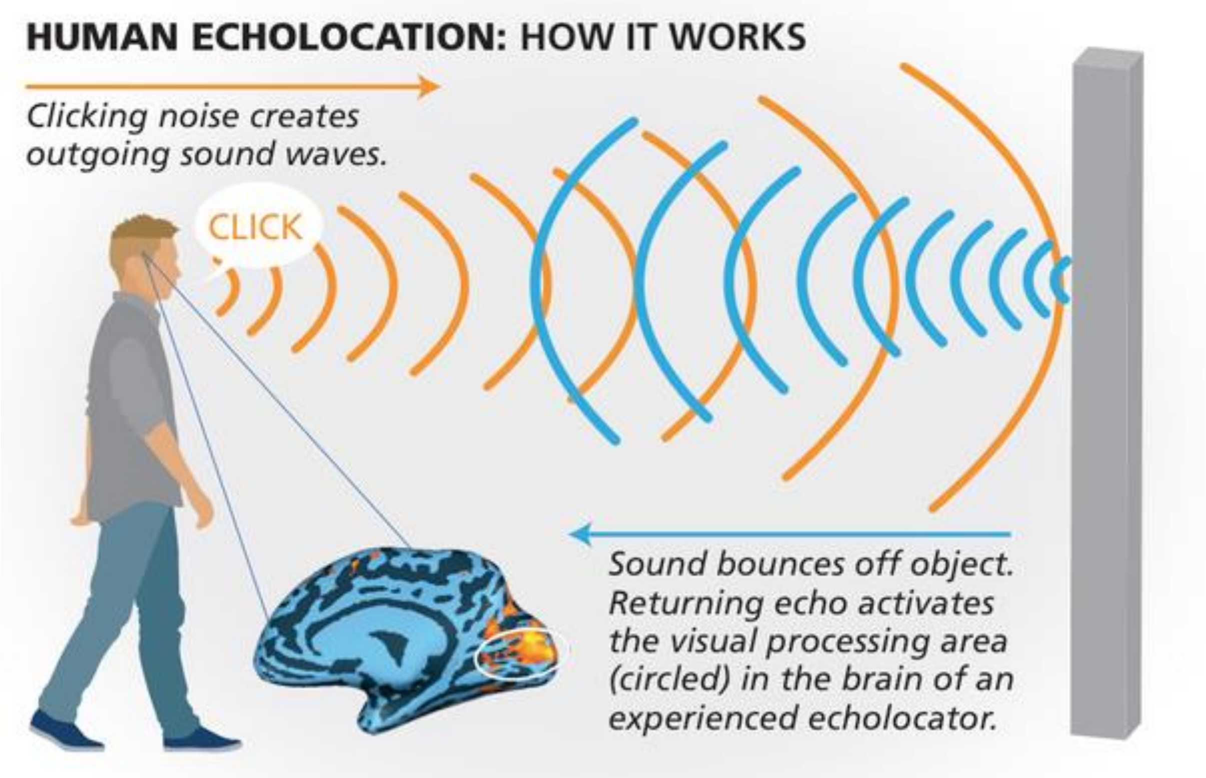
Normal hearing 0 – 20 dB
Slight/mild hearing loss 20 – 40 dB
Moderate hearing loss 40 – 60 dB
Moderate/severe hearing loss 60 – 80 dB
Severe hearing loss 80 – 100 dB
Profound hearing loss 100 – 120 dB

Wind and temperature

- Sound travels with approximately 1 km in 3 sec. (by 20 degrees: 343 m/sec, 1.235 km/hour);
- Sound travels more slowly when it is cold (by -12 degrees: 323 m/sec);
- Sound travels faster, when it is hot (by 30 degrees: 348 m/sec); BUT:
- Sound is louder by ground level in the cold weather; this is because of different temperatures in the air layers, which reflects the sound downwards;
- Visually impaired often hear better in cold weather because of this combined with less reflection because of snow and no leaves on the trees.

Definitions of echolocation

Researchers dealing with psychoacoustics indicate that the basis for auditory spatial orientation of blind people may be the auditory impression resulting from the reflection of the sound from an obstacle. Probably the most important is the assessment of the so-called ’tone of reflection’ that arises from the interference of directly reflected sound (Jorasz, 1998).



Source: http://discovermagazine.com/2015/july-aug/27-sonic-vision

Echolocation is a technique which consciously involves your senses, especially your hearing sense in perceiving and collecting precise information about environmental structures and characters, qualities (materials) in a way so that you can identify an object or a group of objects presented in a given environment (Kish, 2014).

Echolocation is a method of interpreting the sounds created by echoes from surrounding objects in order to determine where the objects are in relation to you.

It is not magic nor does it require special abilities or even years of training. Humans can learn to interpret echoes and sound reverberations to see the world around them with surprisingly little training. Objects from very large to very small can be detected, and this technique can be used to orient one's self and navigate through complex and foreign environments (Johnson, 2012).

Echolocation is an orientation technique and a method to intentionally involve the senses, particularly the hearing, to perceive and gather exact information about the nature and structure of the surroundings to identify an object or a group of objects

that is present in a given setting. Echolocation is a technique making use of the fact that the sound that a person emits will be reflected from the object, that the sound hits and goes back to the person's ears. Thus, it can be perceived by the ear and interpreted by the brain.
However, cholocation cannot replace the use of the long cane but should be used in combination with the cane to complete and supplement the data sensed with the cane. Travelling in this way makes it possible for persons with visual impairments to gather maximum amounts of information about the world and the things in the world surrounding them. Echolocation can help blind people to travel more freely, safer and more independently in known as well as unknown surroundings (Dyekjær, 2014).

Types of echolocation: active and passive echolocation echolocation

There are two forms of echolocation: **active echolocation and passive echolocation**. Both involve the use of sounds to 'see' the world and to form mental images through interpretation of the sound signals or echoes reflected from the surroundings (Dyekjær, 2014).

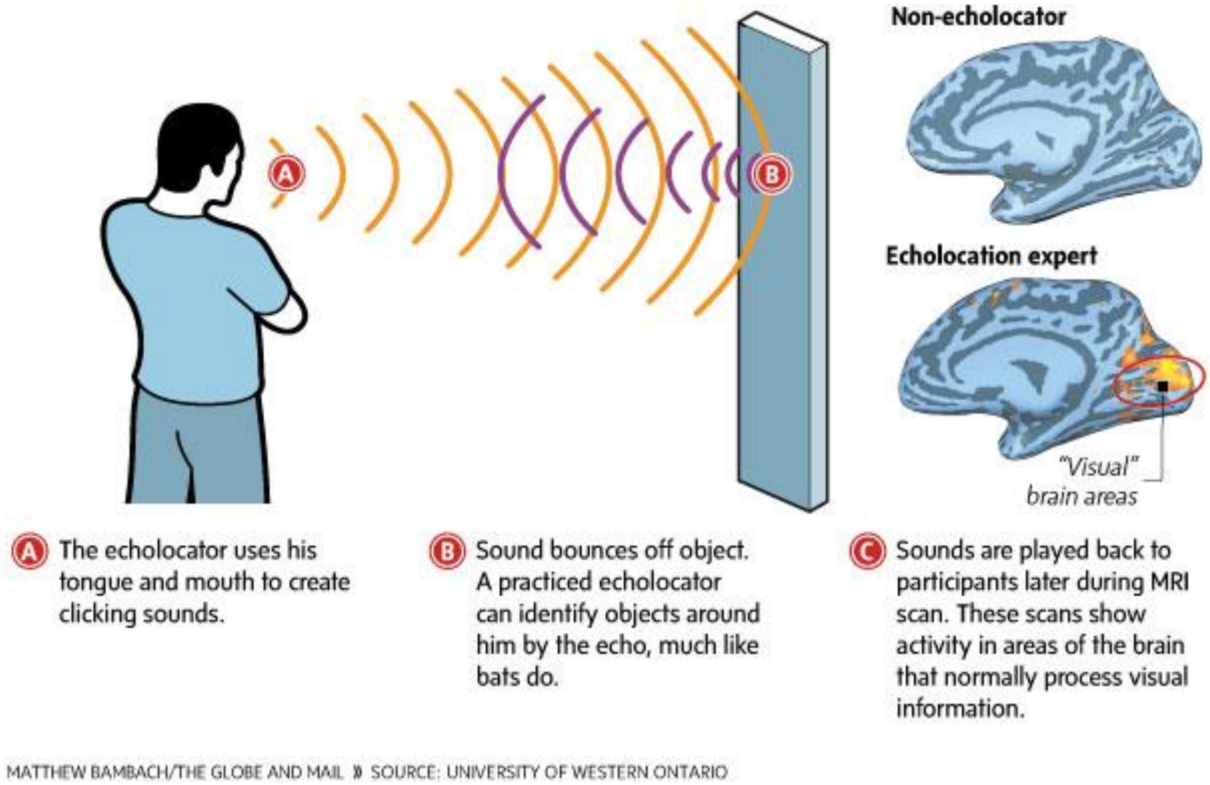
Passive echolocation is the use of the sounds coming from the surroundings – traffic noise, other people's steps, etc. By means of the sounds from the surroundings, it is possible to recognise a location and identify your position in an area. The sounds from the surroundings can be used as points of orientation to get around safely and wisely. For example, a constant sound of engines may indicate that you are approaching a street, etc.

Passive echolocation entails a constant awareness of your body's position in relation to the sound, so that it is possible to perceive and recognise objects and avoid obstacles around you. It is possible to perceive changes in temperature and pressure when approaching the objects.

Passive signaling during echolocation involves listening to the ambient noises in the room and interpreting them. It has its pros, such as not being intrusive or noticeable. These sounds can be:

• people talking;
• a running fan;
• footsteps;
• cane tapping;
• clothes rubbing against each other;
• hands rubbing together;
• breathing;
• machinery & clocks.

Active echolocation is the use of a specific signal sound that is designed and optimized for reflecting off objects. It is a sound that you know and are familiar with and will be able to distinguish the subtleties of how it changes after it interacts with obstacles. Generally, this signal sound is a very short, high-pitched, penetrating sound.



Source: https://sciencebehindsuperpowers.weebly.com/echolocation.html

Active echolocation is the active and conscious production of sounds by a person, for instance with the tongue click sound, snapping/clapping of your fingers/hands. The sound is emitted in a desired direction with a desired power. The emitted sound hits an object and the reflection sound is called an echo. The time, volume, pitch, timbre and distance to and from an object which an echo reflects are decisive for how the echo can be interpreted into a mental representation and conception of the surroundings.

For most proficient echolocators, this sound is made by creating a clicking sound with the mouth. The reason the mouth is used is because it is with you wherever you go. The mouth, being part of the head, is also quite close to the ears, which means that sound travelling outward from it, and thus being reflected off by obstacles, will be travelling directly from and directly to the ears.

Types of echolocation and their effectiveness

Echolocation requires coordination and cooperation of various senses used for obtaining information from the environment and skills to interpret it in order to localize oneself in relation to other objects.

Passive echolocation relies on detecting and identifying sounds occurring in the environment. This ability enables people with visual impairment to detect objects in the space. It also allows you to determine the distance to the detected object and also to identify it. In everyday situations, passive echolocation can be used to notice the presence of people in the room, to detect devices that emit sound (e.g. a fan, TV, car engine, vacuum cleaner, etc.) A condition for using passive echolocation is an efficient hearing organ, having sensitivity to sounds and emitting sound through the object or objects occurring in the environment.

In contrast, active echolocation allows you to detect an object in the space despite the lack of sound. It allows the object to be detected by the conscious emitting of a sound towards the object by a person with sight dysfunction. It allows obtaining more detailed information about the object: its size, shape, material from which the object is made. In everyday situations, active echolocation can be used to determine the size of rooms, corridors, to determine the distance from the walls and to auditory lead along the surface (walls). In the open space, outside for detecting small and large objects (shelter, tree, parked cars). The condition enabling the use of active echolocation is an efficient hearing organ and the ability to emit sound using the mouth, clicks on squares, etc. and the ability to interpret the sound reflected from the objects.

Benefits of active echolocation:

• The use of active echolocation is growing in popularity as a perceptual mobility tool for the blind and visually impaired.

• As more scientific research is compiled, the skepticism around the skill is slowly fading away and making way for accelerated development and implementation of this unique tool.
• Echolocation is a fundamentally simple skill that many blind people use daily to navigate and understand their environment on a broad scale.
• With proper implementation, however, it can be used to identify precise distance, sizes, shapes, edges and even the density of surrounding objects.
• Sound waves like ripples in a pond reflect differently all objects and surfaces. This makes it possible for the trained ear to distinguish the shape, size, distance and material of our surroundings.
• Musicians will tell you that reverb causes each room or surface to have its own unique sound response. With sensitization and applied practice of this skill, it is possible for people with visual impairments all over the world to become increasingly independent, supplementing their existing forms of orientation and mobility with the intrinsic awareness that echolocation can provide.
• Echolocation requires no special equipment nor any special talent. The human body and mind are truly marvels of nature that grant us with capabilities you may never know you have. If you can hear, you can echolocate (Kish, 2017).

Passive and active echolocation may be used together in an integrated fashion. Passive echolocation always happens to some degree, but the images produced are usually mild and unfocused. Active echolocation only occurs when applied by the user, but the resulting images are relatively sharp and extended to much greater distances. In this sense, we may think of passive echolocation like the peripheral vision system which maintains a constant, broad scope of the general environment, acting as a kind of alert system. Active echolocation is, comparatively, like the central vision system in that it allows for the direction of attention toward specific items or features of interest in greater detail and at greater distances.

THE APPLICATION OF ECHOLOCATION IN EVERYDAY SITUATIONS/PRACTICE

Human echolocation is primarily regarded as an active mode of perception. It is an ability to detect, locate and differentiate various types of objects by interpreting acoustic information created as a result of self-generated sound reflected from surrounding objects. It is not an extraordinary ability. It is a skill that anyone can learn.

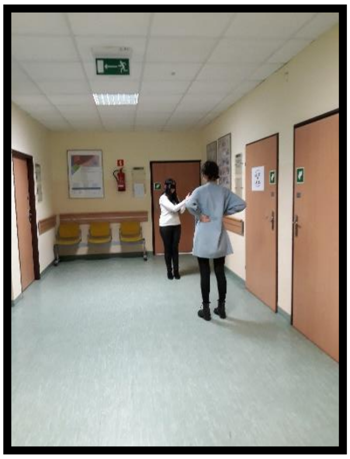
The situation that can help us understand echolocation is this when we sit by the open window while on a train. Sitting inside the train with the window open, we hear objects passing by on the route (trees, traction poles, another train, tunnel, etc.). Hearing of these objects is possible due to the sound produced by the train and reflected from the roadside objects. Then this reflected sound returns through the open window to the passenger.

The environment where visually impaired people use echolocation

Echolocation is a skill that can be used by people with vision dysfunctions in many everyday situations and, therefore, also in many different places. Basically, we distinguish two types of space in which people with vision dysfunction use echolocation. It is a closed space (inside the building) and open space (outside the building).

Closed space (inside the building):

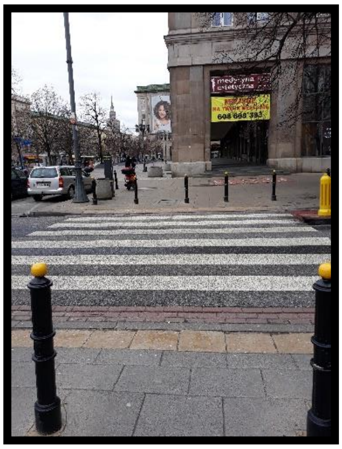
- Flat: room, kitchen, bathroom, bedroom, living room; corridor, garage container;
- public buildings: office, nursery, clinic, theater, shop, stations, etc.



Source: private photos.

Open space (outside the building):

- residential area;
- trade district;
- crossroads;
- city centre;
- shopping centre;
- park, forest



Source: private photos.

Depending on the type of space and the objects occurring in it, echolocation can be used to identify large and small objects.

Large objects:

- buildings;

- walls;
- bus stops;
- cars;
- trees, bushes;
- benches.

Small objects:

- cups;
- balls;
- boxes;
- light;
- vases.

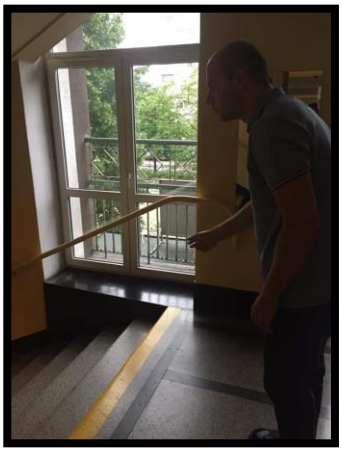
Description of the exemplary situations of the use of echolocation

During the movement of a visually impaired person, there are several ways of moving around. In the subject literature, four basic methods of movement are indicated: with a sighted guide, with a long cane, with a guide dog, with electronic help to support mobility. The choice of how to move depends on many factors. The most important of them are: age, degree of blindness, level of physical fitness, cognitive processes; efficiency in spatial orientation skills, personal preferences of a visually impaired person, familiarity and complexity of the area, etc.
People with vision dysfunction using the skill of echolocation also use one of the above-mentioned ways of moving, most often it is a white cane.

Closed space (inside the building):

- Getting to know the room using echolocation:
    - determining the shape, size of the room;
    - determining whether the room is empty or if there is furniture in it;
    - finding a way out of the room;
- Detecting and locating doors (open, closed) while moving along the corridor;

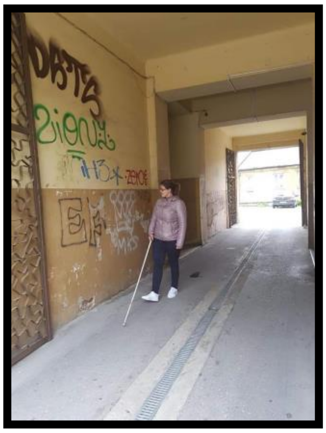
- Detecting and locating staircases, perpendicular cortices;
- Locating obstacles along the route;
- Keeping a constant distance from the wall while moving.



Source: private photos.

Open space (outside the building):

- Locating service points, for example stores (after a characteristic roofing);
- Locating large objects along the route:
  - bus stops;
  - parked cars;
- Locating the ends of building walls, fences;
- Detection of space between buildings;
  - entrance gates;
  - entrances to the parking lot;
- Identifying and locating the passage of underground, tunnels;
- Detecting and avoiding poles, lanterns, springs, bushes.

Source: private photos.

Factors affecting the use of echolocation by visually impaired people

The effectiveness of the use of echolocation by a visually impaired person depends on many factors: the right way to click, the volume of the sound being issued, the volume of sounds in the environment, properly functioning hearing organ, experience in the interpretation of sounds and personal motivation.

An echo signal which is emitted close to the ear sends most of the information about the object it hits back to the ear. This is because the sound is best reflected to the source of the sound, i.e. the mouth, hand, cane or feet.
The tongue click is the most effective echo signal as the sound is produced close to the ear.

- In mastering the skill of echolocation, the **technique of tonque clicking** is very important. It is recommended to click on the tonque. The sound should be very crisp, clear and powerful.

- The **frequency of the sounds produced** is also very important. The tonque clicking should be broadcast not more than every two seconds. The learner needs time to process the information which is returned.

- Interpretation of tonque cliking makes it difficult to hear **additional sounds in the surrounding,** for example: noise, murmur, etc. Loud sounds from the environment make it difficult to interpret the reflected sounds.

- A properly built and functioning **hearing organ** is very important in acquiring echolocation skills. People with hearing loss may also possess this ability but their learning will require more time and modification of the teaching process.

- The internal motivation of the learner is very important in acquiring the skill of echolocation. Internal involvement and openness to learning are the basis for the practice of echolocation skills.

- An extremely important factor in the process of learning echolocation is systematic learning under the guidance of an experienced teacher and independent building of experience through experimentation resulting from the curiosity of the world.

TEACHING ECHOLOCATION

Teaching and learning to use echolocation skills is a very individual process that is focused on the needs and potential of visually impaired people.

Stages of teaching echolocation

We can separate several stages of the teaching process:

I. Conducting a functional assessment, which should consist in gathering information on:

1. Life situation (family life, work, independence, etc.).
2. Blindness of vision (causes of blindness, consequences of sight disability, etc.).
3. Spatial orientation and independent movement (moving techniques).
4. Movement and sensual reception of space (reception of tips and listening, tactile and other landmarks).
5. The motivation to start learning echolocation.

II. Exercises in the field known for checking the techniques of movement, independence.

III. Preliminary exercises focused on the reception of sounds from the environment (locating the sound source, determining the distance from the sound source, identification and description of the sound).

IV. Active echolocation exercises (in rooms with different objects: stationary and moving, inside buildings and outside buildings, etc.).

When we develop echolocation training, we should consider the following rules:

- from stationary exercises to exercises on the move;
- the principle of grading difficulties (from simple to complex exercises);
- from indoor exercises to outdoor exercises;
- from exercises requiring a lot of support to self-reliance exercises.

Below we present a few case studies of teaching echoes to people with additional impairments. We show some recommendations and suggestions how teaching should be adjusted to needs of individuals, including various groups like people with additional impairments (intellectual disability, hearing dysfunction), deaf-blind persons, people with low vision, children, adults, etc.

Case studies

When we analyzed individual case studies, we tried to work according to the following scheme, answering questions:

1. What type of problems/difficulties can the described person have in the context of teaching echolocation? What problems and difficulties do you expect? What are the strengths of this person?
2. List the types/examples of exercises that you would suggest at the beginning of the classes with echolocation.
3. What will be the work specification in the context of teaching echolocation with the person described? Think about the rules of working with a person with this type of disability.

Person I: a visually impaired child

Anna, 4 years old

Anna is a girl in the intellectual norm. She likes running, jumping. The girl has problems with concentration. She has difficulties with concentrating on a longer task. She has a rich vocabulary, she talks a lot and she asks a lot of questions. She does not like when it is very quiet around her but she is afraid of very loud sounds. She moves with a guide. She also uses the push toy to move. She needs a permanent presence of another person.

Strengths: the need for movement (motivation to go out/walk, explore), a rich vocabulary (advantage in describing sounds, creating adjectives).

Weaknesses: problems with concentration and focus on a longer task, the girl does not like silence, fear of loud sounds.

Preliminary exercises with echolocation:

- taming with different sounds (sounds from the environment and those produced by them) in the form of play, e.g. stomping, clapping, clicking;
- producing the ‘szszsz sound, singing, speaking in a whisper or shouting;
- playing with the use of musical instruments, sound toys;
- fun in locating the sound source (learning the sides: ‘right’, ‘left’, learning spatial prepositions).

Tips for working with a person with this type of disability:

- provide your child with a sense of security;
- start classes in a place liked by a child (where he/she feels safe);
- gradate difficulties;
- follow the child;
- give a lot of positive reinforcements;
- take breaks during exercises, (where the frequency of breaks will depend on efficiency in concentration), so that the child does not become discouraged to work;
- activities in the form of fun, to make the child feel pleasure, be curious and at the same time learn echolocation techniques.

Person II: a low vision person

Michał, 15 years old

Michał is a visually impaired person (cataracts, problems with the central field of vision, reduced acuity of vision for a long and short distance, need for additional light). Michał is a rebellious teenager. He does not like movement, walking or any physical activity. He is physically fit. He spends a lot of time in front of the computer and with his smartphone. He is interested in history. He does not like to move in the dark and at dusk. He goes out alone from home but only to known places (school, shop). He does not use a cane. He would like to visit museums (e.g. Polish Army Museum, Warsaw Uprising Museum, etc.), go to various exhibitions.

Strengths: he is interested in a smartphone so you can show him different types of applications for navigation and route planning, e.g. to a selected museum, he wants to visit museums so you can arouse motivation to learn new routes with the inclusion of echolocation as a help in getting self-confidence in new places.

Weaknesses: he does not like movement and walking, may not be interested in producing clicking sounds, not using a white cane.

Preliminary exercises with echolocation:

- exercises using the navigation application, route planning, e.g. to your favorite museum;
- training to move with the use of a white cane.

Tips for working with a person with this type of disability:

- positive motivation;
- give a lot of positive reinforcements;
- exercise during the day, and only later in the dark when ready for it;
- exercises in route planning using urban transport;
- the use of interests (museums, exhibitions) to choose places for echolocation exercises,

Person III: an adult person who has lost her vision

Maria, 40 years old

Maria is a person who has lost her vision. She has glaucoma. She is professionally active, she works as a masseur. She cares about safe, independent movement, especially to the workplace. She does not like noise and very loud sounds. She feels anxiety when she walks alone on the street. She has difficulty interpreting sounds from the environment. She uses a white cane while moving, but her technique is low.

Strengths: willingness to move, for example, to the workplace (this may be a good motivation), a person who is professionally active.

Weaknesses: she does not like noise, very loud sounds; fear when moving around the street, difficulties in interpreting sounds, the technique of moving with a cane on a low level.

Preliminary exercises with echolocation:

- learning to move with the use of a long, white cane;
- psychologist support;
- exercises of interpreting various sounds (in the room you can use sound recordings, then exercises to interpret sounds outside);
- first, exercises in the building, e.g. stationary exercises, moving around corridors, etc.

Tips for working with a person with this type of disability:

- positive motivation;
- give a lot of positive reinforcements;
- first classes in the building;
- gradual taming with independent moving outside;
- early cognitive walks with a guide;
- getting accustomed to sounds, learning to interpret sounds.

Person IV: an adult person with hearing problems

Jan, 57 years old

Jan is a blind person from birth. For 15 years he has had additional hearing problems (hearing loss of a significant degree in the right ear, he wears a hearing aid). He does not work. He loves walks, especially walks to the forest and park. He moves with a white cane, quite uncertainly, the pace of the march is slow. He has problems with the interpretation of sounds from the crowded space, where the capture of words is additionally difficult.

Strengths: he loves walking, which can be a good motivation.

Weaknesses: hearing problems, problems with the interpretation of sounds in a crowded space, uncertainty when moving independently in space, disturbance of spatial orientation (hearing only in one ear).

- preliminary exercises with echolocation;
- gradation of difficulties;
- at the beginning of the exercise in quiet places (e.g. in the park);
- exercise of locating the sound source;
- exercises of interpreting different sounds (in the room you can use sound recordings, then outdoor activities).

Tips for working with a person with this type of disability:

- you should first conduct a functional hearing assessment and then use the hearing potential according to the possibilities;
- taming with all kinds of sounds.

Person V: an adult blind person with physical disability

Barbara, 50 years old

Barbara is a visually impaired person (retinitis pigmentosa), she has tunnel vision.

In addition, she has been moving in a wheelchair for 8 years due to problems with joints. She does not work but is active in the foundation for the visually impaired. She likes visiting new places, especially those related to art and culture (exhibitions, museums, vernissages, etc.). She usually moves in the company of another person.

Strengths: she is an active person and it can be a good motivation.

Weaknesses: moving around in a wheelchair, which will make it difficult to hear at levels below and above, or to control the distance to a given object, e.g. a building.

Preliminary exercises with echolocation

- stationary exercises;
- then moving exercises in the building, it is best to start from a building where there is adequate space for moving in a wheelchair.

Tips for working with a person with this type of disability:

- the space must be adapted to the needs of a person moving in a wheelchair;
- make the person aware that due to his complex disability, he or she will not be able to move around in any place;
- training with a spatial orientation instructor, during which the routes will be developed together, taking into account the space adaptation, individual needs of the person, etc.

Person VI: an adult low vision person with mental disability

Kate, 20 years old

Kate is a blind person. In addition, she is diagnosed with mental disability (a slight degree of disability). She is a student of a vocational school in a special school for the blind. She lives with her parents. She likes listening to music, watching movies, shopping. While moving, she uses a white cane, but moves only in well-known places near the house. She would like to do shopping alone in a local shop.

Strengths: she moves in well-known places, besides, she wants to do shopping independently, which can be a good motivation.

Weaknesses: elated to intellectual disability, e.g. memorisation, interpretation of sounds and their naming.

Preliminary exercises with echolocation

- stationary exercises;
- exercises moving around in a building, navigating in a known space;
- distinguishing, naming, locating sounds;
- interpreting traffic;
- development of the route, for example, to the estate shop.

Tips for working with a person with this type of disability:

- difficulties should be graded;
- the principle of small steps;
- checking if a person understands commands during exercises, building commands using simple formulations understood by the person;
- checking if the person remembers the information provided during the class;

- a lot of fixing, repeating;
- positive reinforcements.

REFERENCES

Books

Dolański W. (1954). *Czy istnieje "zmysł przeszkód" u niewidomych*. Warszawa: PWN.

Johnson T. (2012). *Beginner's guide to echolocation for the blind and visually impaired. Learning to See with Your Ears.* Create Space Independent Publishing Platform.

Kish D., Hook J. (2016). *Echolocation and Flash Sonar.* American Printing for the Blind.

Kuczyńska-Kwapisz J., Śmiechowska-Petrovskij E. (2017). *Orientacja przestrzenna i poruszanie się osób z niepełnosprawnością wzroku. Współczesne techniki, narzędzia i strategie nauczania*, Warszawa: UKSW.

Oosterhoff den-Oudendammer, Mirjam et al (2010). *Deel 2 Vaardigheden Echolokalisatie*. Koninlijke Visio, Revalidatie en Advies, Expertisecentrumvoor slechtziende en blinde mensen, Heerbaan 14-40, 4817NL Breda. Holland 2010.

Roberts J. (2006). *A Sense of the World: How a Blind Man Became History's Greatest Traveler.* New York: Harper Collins Publishing.

Swierłow W. (1957). *Orientacja niewidomych w przestrzeni*. Warszawa: PZWS.

Wereda H. (2012). *Niech Cię słuch prowadzi.* Warszawa: Biblioteka Centralna Polskiego Związku Niewidomych.

Articles

Ammons C.H., Worchel, P., & Dallenbach, K.M. (1953). *"Facial Vision": The perception of obstacles out of doors by blindfolded and blindfolded-deafened subjects.* American Journal of Psychology, 66(4), 519-553, DOI: 10.2307/1418950

Arias C, Ramos O.A., (1997). *Psychoacoustic tests for the study of human echolocation ability. Applied Acoustic*, 51, pp. 399–419.

Arias C, Fernando Bermejo F., Hüg M. X., Venturelli N., Rabinovich D., Skarp A.O. (2012). *Echolocation: An Action-Perception Phenomenon*, New Zealand Acoustics, 25, (2), pp. 20–27,

Ashmead D.H., Hill E.W., Talor, C.R. (1989). *Obstacles Perception by Congenitally Blind Children.* Perception and Psycho-Physics, 46, pp. 425–433.

Ayrapetyants E.Sh., Konstantinov A.I. (eds.) (1974). *Echolocation in Nature.* Joint Publications Research Service: Arlington, Virginia.

Bassett, I.G., Eastmond E.J. (1964). *Echolocation:* Measurement *of pitch vs. distance for sounds reflected from a flat surface.* Journal of the Acoustical Society of America, 36, pp. 911–916.

Boehm R. (1986). *The Use of Echolocation as a Mobility Aid for Blind Persons*. Journal of Visual Impairment and Blindness, 80(9), pp. 953–954.

Bujacz M. et al. (2018). EchoVis: *Training Echolocation Using Binaural Recordings – Initial Benchmark Results*. In: Miesenberger K., Kouroupetroglou G. (eds) Computers Helping People with Special Needs. ICCHP 2018. Lecture Notes in Computer Science, 10897. Springer, Cham.

Cotzin M., Dallenbach K.M. (1950). *Facial Vision: The role of pitch and loudness in the perception of obstacles by the blind.* American Journal of Psychology, 63(4), pp. 485–515.

Dufour A., Desprs O., Candas V., (2005). Enhanced sensitivity to echo cues in blind subjects, Experimental Brain Research, 165(4), pp. 515–519.

Ekkel M.R., Lier R. V, Steenbergen (2017). *Learning to echolocate in sighted people: a correlational study on attention, working memory and spatial abilities. Experimental Brain Research,* 235(3), 809–818, DOI: 10.1007/s00221-016-4833-z.

Goodale M. A. (2013). *Po co mózg widzi?*, „Charaktery", 2, pp. 44–45.

Hausfeld S., Power R.P., Gorta A., Harris P. (1982). *Echo Perception of Shape and Texture by Sighted Subjects.* Perceptual Motor Skills, 55(2), 623-632, DOI: 10.2466/pms.1982.55.2.623.

Kellogg W.N. (1962). *Sonar System of the Blind*. Science, 137(3528), 399-405, DOI: 10.1126/science.137.3528.399.

Kolarik A.J., Cirstea S., Pardhan S., Moore B.C. (2014). *A summary of research investigating echolocation abilities of blind and sighted humans*. Hear Res. 10:60–68, DOI: 10.1016/j.heares.2014.01.010.

Kuc R., Kuc V., (2016). *Modeling human echolocation of near-range targets with an audible sonar. The Journal of the Acoustical Society of America,* 139, 581 https://doi.org/10.1121/1.4940668.

Ladefoged P., Traill A. (1993). *Clicks and Their Accompaniments*. Journal of Phonetics, 22 (1), pp. 33–64.

Middlebrooks J.C., Green D.M. (1991). *Sound Localization by Human Listeners*. Annual Review of Psychology, 42, pp. 135–159.

Miler-Zdanowska (2019). *Echolokacja - metoda wspierająca orientację przestrzenną i samodzielne poruszani się osób z niepełnosprawnością wzroku, Interdyscyplinarne Konteksty Pedagogiki Specjalnej*, (w druku)

Neff F. E., Pitt I. (2008). *Investigating the potential of human echolocation in virtual sonic trigonometry*, The Journal of the Acoustical Society of America, 123(5), pp. 3725–3725.

Nillson M.E., Schenkman N. (2016). *Blind people are more sensitive than sighted people to binaural sound-location cues, particularly inter-aural level differences*. Hearing Research, 332, pp. 223–232.

Norman L.J. Thaler L. (2018). *Human Echolocation for Target Detection Is More Accurate with Emissions Containing Higher Spectral Frequencies, and This Is Explained by Echo Intensity*, “i-Perception”, 9 (3), pp. 1–18.

Ono H., Fay A., Tarbell S.E. (1986). *A "Visual" Explanation of Facial Vision. Psychological Research*, 48(2), pp. 57–62.

Papadopoulos T, Edwards D.S., Rowan D., Allen R. (2011). *Identification of auditory cues utilized in human echolocation—objective measurement results. Biomed Signal Process Control*, 6, pp. 280–290.

Pelegrin-Garcia D., Rychtáriková G.M. (2016). *Audibility thresholds of a sound reflection in a classical human echolocation experiment.* Acta Acustica united with Acustica, 102, pp. 530–539.

Rice C.E., Feinstein, S.H. (1965a). *Sonar System of the Blind: Size discrimination*. Science, 148, pp. 1107–1108.

Rojas J.A.M., Hermosilla J.A., Montero R.S., Espí P.L.L. (2009). *Physical Analysis of Several Organic Signals for Human Echolocation: Oral Vacuum Pulses***.** Acta Acustica united with Acustica, *95 (2), 325 – 330,* DOI: 10.3813/AAA.918155.

Rojas J.A.M., Hermosilla J.A., Montero R.S., Espí P.L.L. (2010). *Physical analysis of several organic signals for human echolocation: hand and finger produced pulses*. Acta Acustica united with Acustica, 96, pp. 1069–1077.

Rowan D., Papadopoulos T., Edwards D., Holmes H., Hollingdale A., Evans L., Allen R. (2013). *Identification of the lateral position of a virtual object based on echoes by humans*. Hearing Research, 300, pp. 56–65.

Rowan D., Papadopoulos T., Edwards D., Allen R. (2015). *Use of binaural and monaural cues to identify the lateral position of a virtual object using echoes*. Hearing Research, 323, pp. 32–39.

Schenkman B., Jansson G. (1986). *The Detection and Localization of Objects by the Blind with the Aid of Long-Cane Tapping Sounds.* Human Factors, 28(5), pp. 607–618.

Schenkman B., Nillson M.E., (2010). *Human echolocation: Blind and sighted persons' ability to detect sounds recorded in the presence of a reflecting object*, "Perception", 39.

Schenkman B. (2017). *Human echolocation in different situations and rooms*. The Journal of the Acoustical Society of America, 141, (5). 3452-3452, DOI: 10.1121/1.4987156.

Stoffregen T.A., Pittenger J.B. (1995). *Human echolation as a basic form of perception and action,* Ecological Psychology, 7, 181216.

Supa, M. Cotzin, M., Dallenbach, K.M. (1944). *Facial vision, the perception of obstacles by the blind.* American Journal of Psychology, 57, pp.133–183.

Theng S., Whitney D., (2011). *The acuity of echolocation: Spatial resolution in the sighted compared to expert performance*, Journal of Visual Impairment & Blindness, 105(1), pp. 20–32.

Teng S., Puri A., Whitney D. (2012). Ultrafine spatial acuity of blind expert human echolocators. Experimental Brain Research, 216, pp. 483–488.

Thaler L., Arnott S.R., Goodale M. A. (2010). *Human Echolocation I*. Journal of Vision, 10 (7), 1050 – 1050, DOI: 10.1167/10.7.1050.

Thaler L. (2013). *Echolocation may have real-life advantages for blind people: an analysis of survey data*. Frontiers Physiology, 4, 98. DOI: 10.3389/fphys.2013.00098.

Thaler L., Melvyn A. G. (2016). *Echolocation in humans: an overview*. WIRes Cognitive Science, 7, 382-393, DOI: 10.1002/wcs.1408.

Thaler L., Castillo-Serrano J. (2016). *People´s ability to detect objects using click-based echolocation: a direct comparison between mouth-clicks and clicks made by a loudspeaker*. PLOSONE, 11 (5) doi.org/10.1371/journal.pone.0154868.

Thaler L., Goodale M. A. (2016). *Echolocation in humans: an overview. Wiley Interdisciplinary Reviews Cognitive Science*, 7, 382-393. DOI: 10.1002/wcs.1408.

Thaler L., Reich G.M., Zhang, X., Wang D., Smith G.E., Tao, Z., et al., (2017). *Mouth-clicks used by blind expert human echolocators- signal description and model-based signal synthesis*. PLOS Computational Biology, 13, e1005670.

Norman L.J., Thaler L. (2018). *Human Echolocation for Target Detection Is More Accurate With Emissions Containing Higher Spectral Frequencies, and This Is Explained by Echo Intensity*, i-Perception, DOI: 10.1177/2041669518776984.

Wallmeier L., Kish D., Wiegrebe L., Flanagin V.L. (2015). *Aural localization of silent objects by active human biosonar: neural representations of virtual echo-acoustic space*. European Journal of Neuroscience, 41, pp. 533–545.

Wiener W.R., Lausen G.D. (1997). *Audition for the Traveler Who Is Visually Impaired.* in B.B. Blasch, W.R. Wiener, R.L. Welsch, (eds.) Foundations of Orientation and Mobility. A.F.B. Press: New York, pp. 104–169.

Witek P., Rozborska A., Waszkielewicz A., Rotnicki M., Brayda L. (2016). *Echolokacja - mit czy istotny element rehabilitacji osób z niepełnosprawnością wzroku W: Tyflopedagogika wobec współczesnych potrzeb wspomagania rozwoju, rehabilitacji i aktywizacji społecznej* (red.). M. Paplińska, M. Walkiewicz-Krutak, Warszawa: Wydawnictwo APS.

Walkiewicz-Krutak M. (2019). Aktywna i pasywna echolokacja jako element percepcji słuchowej i orientacji przestrzennej osób niewidomych, *Niepełnosprawność. Dyskursy Pedagogiki Specjalnej,* nr 34, pp. 11–2.

Vercillo T., Milne J.L., Gori M., Goodale M.A. (2014). *Enhanced auditory spatial localization in blind echolocators.* Neuropsychologia. 67C, pp. 35–40.
DOI: 10.1016/j.neuropsychologia.2014.12.001 .

Websites and other materials

Blog Jonhson, T. (2014). http://learnecholocation.blogspot.com.
Dyekjaer, L. O&M – Flash sonar/ ekkolokalisering. A tutorial for O&M instructors in Denmark.

Hansen, R.E. (2012). Introduction to sonar Course materiel to INF-GEO4310, University of Oslo.

Hełm Sonic Eye (2018) https://gadzetomania.pl/56983,helm-sonic-eye-rozszerza-nasze-zmysly-o-echolokacje-uslysz-swiat-jak-nietoperz [access: 20.05.2018].

human echolocation (2018). https://en.wikipedia.org/wiki/Human_echolocation [access: 15.05.2018].
James Holman (2018). https://en.wikipedia.org/wiki/James_Holman [access: 13.06.2018].

James Holman (2018) https://en.wikisource.org/wiki/1911_Encyclop%C3%A6dia_Britannica/Holman,_James [access: 15.06.2018].

Kish D. (1995). Evaluation of an echo-mobility program for young blind people. Theses Digitization Project. 1036. http://scholarworks.lib.csusb.edu/etd-project/1036

Koninlijke, V. (2010). Part of teaching material in echolocation developed in 2010 by dutch O&M specialists. Holland.

Scientists Develop Echolocation in Humans To Aid The Blind https://www.sciencedaily.com/releases/2009/06/090630075445.htm.

World Access for the Blind (2018) https://visioneers.org/ [access: 09.05.2018

World Access for the Blind (2018) http://waftb.net/ [access: 10.05.2018].