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Comparison of Echolocation Abilities of Blind and Normally Sighted Humans using Different Source Sounds

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Abstract The ability of some humans to echolocate has become widely known primarily due to a small number of famous expert echolocators who are capable of extraordinary feats. However, a lesser-known fact is that all humans exhibit this skill unconsciously and can learn it relatively quickly and implicitly through repeated practice. In our experiments we tested groups of 12 blind and 14 sighted untrained participants in a simple echolocation test – localizing a 1m x 2m vertical wall at distances between 1 and 3 meters using 10 different types of sounds as the source signals for the echolocation attempts. There were significant differences between the participant groups and between some of the tested sounds. Although the groups were small, a clear difference was also observed between the experienced totally blind participants and the legally blind visually impaired participants that had residual light sensitivity. From the compared sounds 3 kHz and 4 kHz synthetic percussion sounds, pink and blue noise were among the sources that led to the highest chances of correctly guessing the obstacle's direction and distance.

Keywords: echolocation, blindness, visual impairment.

1. Introduction

The phenomenon of echolocation is primarily associated with animals such as bats; however, with practice humans can also acquire this skill, especially if it helps them overcome a disability. Although our sense of hearing tends to automatically ignore echoes, more and more research shows that with very little training the ability to echolocate can be "unlocked" [1] and trained [2].

An interested reader can find several review papers on human echolocation. Daniel Kish [1], a world-famous echolocator and echolocation instructor, has prepared an extensive review of early echolocation research, focusing on practical studies and advice for training programmes. More recent reviews by Arias, Kolarik and Thaler. Arias [3] describes echolocation as an "action-perception phenomenon" which can be implicitly learned. Kolarik [4] focuses on how blindness affects hearing and how experienced echolocators develop supranatural abilities, but only in some aspects of auditory perception (e.g. subjective distance assessment, but not objective distance assessment). Thaler and Goodale [5] among other echolocation-related research write about the emission signal, i.e. mouth click, of expert echolocators and the neural underpinnings of echolocation, especially the plasticity of the brain to adapt visual areas to process echolocation signals.

A large body of research has also been devoted to the perceptual restructuring brought on by the loss of vision, and it is now clear that only very specific auditory tasks, such as monaural direction sensitivity, are actually enhanced among the blind [6].

In the presented project the authors conducted a study focusing on the influence of sound source signal type on the echolocation performance of blind and normally sighted individuals. The paper focuses on the differences between blind echolocators and sighted novices, with an additional analysis of visually impaired individuals that retained partial light sensitivity. Some of the author's previous studies were primarily aimed at developing the methodology for echolocation testing and estimating the expected success levels [7-8].

2. Experimental setup

The echolocation tests were performed by 12 blind and 14 sighted participants, aged 26 to 62 (average 39) 14 female and 12 male. The blind testers were divided into two subgroups – totally blind and visually impaired (legally blind but with some partial light sensitivity).

The testers tried to guess the position (distance and direction) of a 2x1m reflective wall that could be placed in nine possible locations as shown in Figure 1. To ensure test fairness testers with healthy sight or residual light sensitivity were blindfolded. Every time the wall was being repositioned the testers wore sound blocking headphones and counted out loud to mask any sounds of the movement.

The testers made a first guess as to the direction and distance to the wall after generating a single sound and listening to the echo. Afterwards, they were allowed *N* (up to 10) additional sound signal repetitions until they felt they could either confirm their answer or wanted to change it. In addition, the participants also answered how certain they were in their answer on a scale from 1 to 5 (1 being "guessing at random", 5 being "fully certain"). The process was repeated with 10 different sounds in a random order (9 attempts for each sound).

The sounds were either played back from a UE Roll 2 speaker hung on the participant's neck, generated using a mechanical dog-training clicker or were the participant's "own sound" – either a palatal mouth click or hand clap. The sounds included five different percussive sounds from 1 to 5 kHz, blue noise, pink noise, synthetic expert echolocator's click, the mechanical clicker and the participant's "own sound". The five percussion sounds were synthesized using the classic Risset drum algorithm with a 2 kHz wide band-filtered noise and base frequencies from 1 to 5 kHz [9]. The expert echolocator's click was synthesized using a Matlab script EE2 available as supplementary material from [10].

The participants also underwent basic audiogram testing and the majority had normal healthy hearing. Interestingly, the few testers that had some significant hearing loss, turned out to be either among the best or worst echolocators, leading to no statistically significant correlations to be found between hearing loss and correctness in obstacle detection.

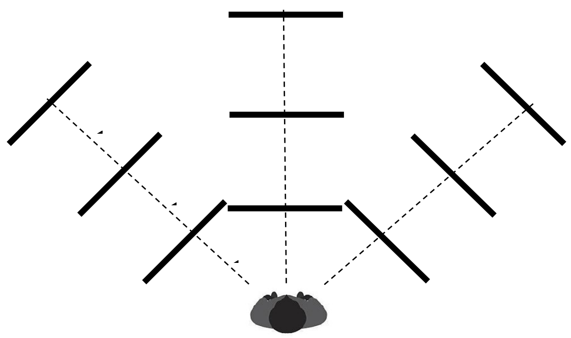

Figure 1. Experimental setup – 1m wide wall was placed at distance 1-3m at one of nine possible locations. The blind (or blindfolded) tester emitted a sound from a Bluetooth speaker held at chest level and guessed the obstacle's location first after a single sound, then after *N* (up to 10) signal repetitions.

3. Results

Statistical ANOVA and Mann-Whitney U Tests were performed to see where significant differences could be observed, either between various participant groups or between the utilized sounds. Due to large standard deviations, not all differences were statistically significant; however, quite a few pair-wise significant comparisons could be made.

Totally blind echolocators were significantly better than both visually impaired (legally blind) and the sighted test participants, by 28% and 31% respectively (p=0.001 and p=0.0004). The difference between the sighted and the visually impaired participants was not significant, showing that even completely untrained sighted persons can echolocate almost as good as untrained legally blind. The results for all participants averaged for all the ten sounds are summarized in Table 1.

The plots in Figures 2 and 3 visualize a few interesting differences between the tested groups and trends in the results. There were significant differences in certainty between the sighted and blind participants, with the latter correctly assessing their higher correctness. There was also a strong trend of increasing certainty with correctness when looking at all the participants. The chance to correctly answer on both direction and distance was 11%. With each participant giving 90 answers, the threshold of non-random answers was 15 out of 90, i.e. 17% average correctness. All but one participant cleared that threshold when looking at correctness after *N* guesses.

Another interesting observation is that additional signal repetitions did not improve the correctness for the best and the worst echolocators. However, those in the middle of the distribution exhibited similar improvements in the correctness of their guesses.

A detailed comparison of the differences between the tested sounds and their results will be the subject of another paper. In summary, of the ten tested sound sources, the top ones were 3 kHz and 4 kHz percussion, as well as blue and pink noise. There were no significant differences between the best sounds, but a significant advantage over the worst sources, especially the mechanical clicker, 1 kHz and 2 kHz percussion and the participants' own sounds (only in the case of the sighted and visually impaired participants).

Table 1. Comparison of the average correctness for participants from the three groups.

	Correctness after first guess			Certainty after first guess
	Direction	Distance	Both	
Totally blind	84%	73%	65%	3.8
Visually Impaired	62%	54%	37%	2.8
Normally Sighted	62%	52%	34%	1.4

	Correctness after N signal repetitions			Certainty after N	Average *N*
	Direction	Distance	Both		
Totally blind	91%	78%	73%	4.1	3.7
Visually Impaired	67%	63%	45%	3.1	7.3
Normally Sighted	72%	60%	48%	1.8	6.3

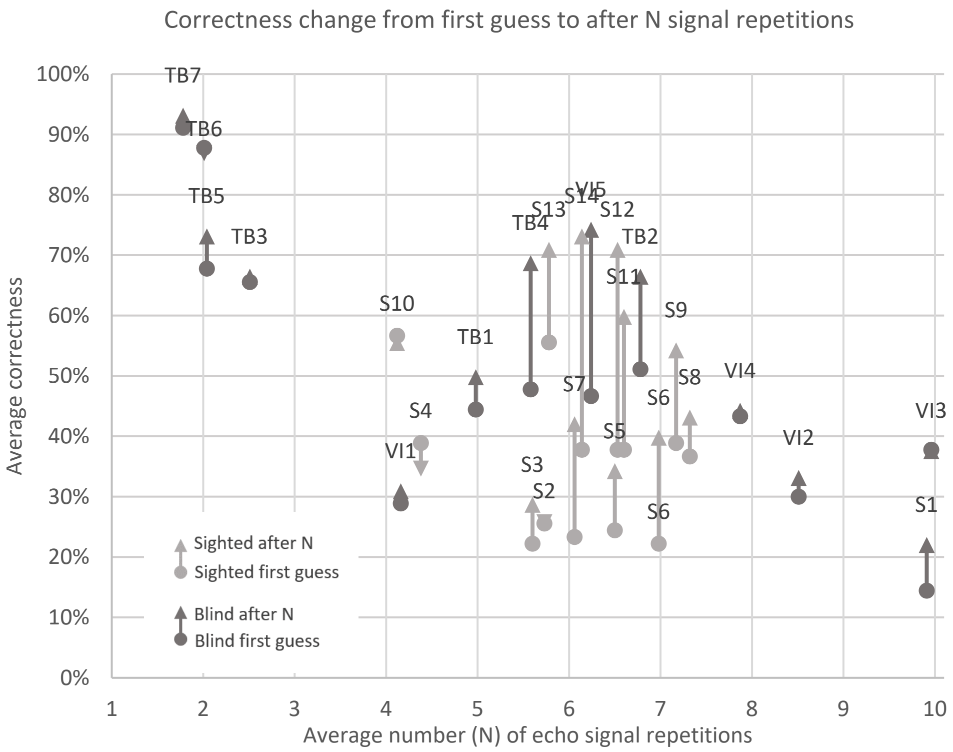

Figure 2. Correctness change after *N* echo signal repetitions for all 26 participants and their average *N* (TB – totally blind, VI – visually impaired, S – normally sighted).

Figure 3. Averaged correctness change after *N* echo signal repetitions for all 26 participants and their average certainty. (TB – totally blind, VI – visually impaired, S – normally sighted).

4. Conclusions

The main conclusion that can be drawn from the presented trials is that nearly all humans can echolocate significantly above random and are quite accurate at judging their correctness. While experienced totally blind testers performed extremely well, those that were only legally blind and could rely on residual light sensitivity performed on average the same as participants that were normally sighted and never had to utilize echolocation.

The sound comparison showed that pink and blue noises along with 3 kHz and 4 kHz percussion were significantly best for accuracy of the echolocation. It is probably related to the highest sensitivity of the human ear in this range. The sense of hearing is most sensitive to mid frequencies, thus these sounds performed best with novices. However, despite the high effectiveness of noise sounds in our study, they were rated as the least pleasant in the post-test survey.

The results confirm that echolocation is a real skill that can be exhibited by any human, can be trained and improved [11]. People who have had to struggle with visual impairment for a long time generally do better with echolocation. It is the result of training and experience. With many of the legally blind patients aware that their impairment is progressing toward total blindness it may be beneficial to begin echolocation training as soon as possible.

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Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

References

1. D. Kish; Sonic Echolocation: A modern Review and Synthesis of the Literature; World Access for the Blind, 2003. Available at: https://worldaccessfortheblind.net/sites/default/files/echolocationreview.htm (accessed: 25.07.2022).
2. L.J. Norman, C. Dodsworth, D. Foresteire, L. Thaler ; Human click-based echolocation: Effects of blindness and age, and real-life implications in a 10-week training program; PLoS ONE, 2021, 16(6), e0252330. DOI:10.1371/journal.pone.0252330
3. C. Arias, F. Bermejo, M.X. Hüg, N. Venturelli, D. Rabinovich, A.O. Skarp; Echolocation: An Action-Perception Phenomenon; New Zealand Acoustics, 2012, 25(2), 20-27.
4. A.J. Kolarik, S. Cirstea, S. Pardhan, B.C.J. Moore; A summary of research investigating echolocation abilities of blind and sighted humans; Hearing Research, 2014, 310, 60–68. DOI:10.1016/j.heares.2014.01.010
5. L. Thaler, M.A. Goodale; Echolocation in humans : an overview; Wiley interdisciplinary reviews: cognitive science, 2016, 7 (6), 382-393. DOI:10.1002/wcs.1408
6. A.J. Kolarik, S. Pardhan, B.C.J. Moore; A framework to account for the effects of visual loss on human auditory abilities; Psychol Rev., 2021, 128(5), 913-935. DOI:10.1037/rev0000279.
7. M. Bujacz et al.; EchoVis: Training Echolocation Using Binaural Recordings – Initial Benchmark Results; In: Computers Helping People with Special Needs; Miesenberger K., Kouroupetroglou G. (eds); ICCHP 2018. Lecture Notes in Computer Science, Springer, Cham., 2018, 10897. DOI:10.1007/978-3-319-94274-2_15
8. M. Bujacz, A. Królak, G. Górski, K. Matysik, P. Witek; Echovis – A collection of human echolocation tests performed by blind and sighted individuals: A pilot study; British Journal of Visual Impairment, 2022. DOI:10.1177/02646196221116728
9. S. Jones; Risset Drum Audacity Plug; In https://github.com/audacity/audacity/blob/master/plug-ins/rissetdrum.ny (accessed on 22.07.2022)
10. L. Thaler, G.M. Reich, X. Zhang, D. Wang, G.E. Smith, Z. Tao, R.S.A. Abdullah, R. Bin, M. Cherniakov, C.J. Baker, D. Kish, M. Antoniou; Mouth-clicks used by blind expert human echolocators – signal description and model based signal synthesis; PLOS Computational Biology, 2017, 13(8), e1005670. DOI:10.1371/journal.pcbi.1005670
11. K. Miler-Zdanowska; Echolocation, as a method supporting spatial orientation and independent movement of people with visual impairment; Interdyscyplinarne Konteksty Pedagogiki Specjalnej (Interdisciplinary Contexts of Special Education) 2019, 25, 353-371. DOI:10.14746/ikps.2019.25.15