

# Echolocation training and improving general cognitive abilities- a literature review

## Abstract

The aim of this study was to review studies on echolocation in humans, how it can be trained how this training is a possible candidate for improving general cognitive abilities. Previous research pertaining to both individual differences in echolocation and the effects of learning new skills on cognitive abilities was outlined. Gaps in this research relating to studying direct links between echolocation training and cognitive improvement were identified. Methods for training echolocation both in real life and virtual settings were outlined alongside cognitive tests used previously in relevant literature that would be suitable for measuring aspects of cognition alongside echolocation. In addition, the importance of driving research into cognitive interventions for those suffering with diseases such as dementia was discussed in terms of where echolocation training could fit in should future research yield positive results. Directions for future research in terms of structure (time frames, participants) was outlined and some implications of possible research outcomes have been identified.

## Introduction

### Echolocation in humans

Echolocation, learning about the location and characteristics of objects within one's surroundings through sound, is something most people would associate with animals such as dolphins and bats or even killer whales (Thaler, 2015; Harmon, 2010). Yet, recent significant research has demonstrated how visually impaired human individuals also use echoes to efficiently detect objects in their environment. Human echolocation goes beyond simple object detection, studies have shown expert echolocators can distinguish size, shape, orientation, motion and even texture using echoes primarily from mouth clicks but also using foot stomps and other sounds from their surroundings (Thaler & Goodale, 2016).

The fixed distance between the eyes and the ears means that mouth clicks are non-varying in comparison to other sounds that would be context dependent, therefore easier to reproduce and detect changes in the environment, mouth clicks are therefore very common amongst echolocators (Thaler, 2015). Mouth clicks can be relatively easy to produce and utilise once taught how, yet a lack of training on how to do so is available, with most being limited to rehabilitation centres with poor systematic guidelines (Ekkel et al., 2016). Many blind echolocators are therefore self-taught, lots from a young age.

In blind expert echolocators, there seems to be a correlation between ability level and the age at which vision was lost, with some individuals who lost their sight at early age having ability similar to that of echolocation specialised species (Teng et al., 2011). In terms of neural correlates, research suggests that echolocation processing involves the activation of visual cortical areas, such as the temporal-occipital cortex (Thaler et al., 2014). Furthermore, some illusions are experienced in both echolocation and vision in sighted individuals, such as the size-weight illusion (Buckingham et al., 2014). Both findings indicate

that echolocation can be integrated into the sensory system in a similar fashion as vision (Buckingham et al., 2014 ; Thaler et al., 2014).

Such evidence has beneficial implications for those with no or impaired vision and would slot in well as a positive addition to other assistance methods such as canes or guide dogs.

Aside from the benefits for blind individuals in their day-to-day life. Echolocation additionally provides a means of gaining insight into cognitive changes related to novel sensory processing (Thaler, 2015).

### Improving general cognitive abilities

Research has shown speech and language learning to have potential cognitive benefits. Bak et al (2016) demonstrated that a short but intense Gaelic language course had a significant positive effect on attentional switching performance (Bak et al., 2016). Participating students underwent 14 hours of Gaelic language training over a week-long period, also being offered additional Gaelic language entertainment in the evenings as enrichment. Before and after the training they were administered the Test of Everyday Attention (TEA) which measures different attentional components. Results of re-testing post- language training show a significant improvement in response accuracy after completing language training (Bak et al., 2016). Furthermore, related study into music training of comparable intensity and duration shows similar improvement in tasks of executive function, like visual search for example (Janus et al., 2016). Such result suggests that perhaps there is an importance in novelty, intensity and duration of practice when learning a new skill that may help improve or maintain cognitive functions of the brain (Bak et al., 2016 ; Janus et al., 2016).

These results provide promise of an alternative to current ‘brain training’ games and subscriptions that do not fully live up to their claims of improving cognitive performance, even after 10 weeks of use (Kable et al., 2017). Even with the effects seen in language learning, the suitability of this training is limited. For some individuals language might not be accessible or easily leaned, for example in the instance of visual impairment or damage/decline in key language brain areas (Sabatin, 2015 ; Bak et al., 2016).

Thus, returning to echolocation, it is possible that this could provide a beneficial alternative training exercise in the context of cognition. Echolocation requires no language use, no vision and can be relatively easy and enjoyable to learn in a similarly short intense course (Thaler, 2015).

### The role of cognition

Relating to more general auditory processing, it is well established that differences in cognition play a critical role in top-down processing during auditory tasks (Ekkel et al., 2016). For example, working memory (WM) capacity is correlated with the ability to accurately localize sound (Moossavi et al., 2014). Furthermore, WM benefits using contextual information in speech recognition (Besser et al., 2013). This suggests that active cognitive processes involving WM are highly influential in auditory processing.

Thus, it would be reasonable to presume that cognitive functions are also highly relevant to echolocation processing. Such hypothesis is given significant support by research that shows central cognitive processes are involved in the use of echo suppression mechanisms (Wallmeier et al., 2013).

The effects of echolocation training on general cognitive abilities has not yet been directly investigated, but there has been some inquiry into correlations between cognitive abilities and individual differences in the ability to echolocate itself (rather than the effect of practice).

There are significant cognitive differences between those who perform particularly well on echolocation tasks and those who do not. Study of echolocation and cognitive abilities has shown high performing echolocators score higher on measures of reaction time, verbal learning and WM digit span (Anderson, 2010). Other research has demonstrated a positive correlation between degree of echolocation improvement over trials and scores of sustained and divided attention (Ekkel et al., 2016).

While these findings introduce some cognitive aspects of echolocation, there are many factors left open for further investigation. These studies test limited aspects of cognitive performance, to fully investigate echolocation's effect on general cognitive abilities, it would be beneficial to administer a wider range of tests (Anderson, 2010 ; Ekkel et al., 2016). Given the findings regarding cognition and auditory processing, as well as cognitive improvements seen after language and music training, opportunity for investigating the effects of echolocation training on general cognitive ability is apparent. It is possible that echolocation training can improve aspects of cognition. Previous evidence shows a negative correlation between echolocation ability and the age at which it started to be used (Teng et al., 2011). Thus, this research can additionally look at differences on effect between age groups and different types of training task.

Findings of such research have the potential to demonstrate how echolocation training can be used as an alternative for commercial brain training programmes. It can be accessible to those with or without vision, as a method of fighting against age related cognitive decline or aid recovery after illness/brain damage.

## Methods

### Participants

Based on previous research regarding brain training and cognitive performance, a minimum sample size of N=60 would be ideal to achieve reliable results. 30 participants in a control and 30 in an experimental group allows for comparison between echolocation training and no training.

Echolocation ability seems to be heightened in non-sighted individuals who lost their vision at a younger age (Teng et al., 2011). Therefore, age of participants will potentially have an effect on learning echolocation through training tasks. It would be beneficial to see how echolocation learning effects cognition in sighted people of different ages, an ideal sample will have a wide age range, even better two age groups of older and younger participants to allow for comparisons to be made.

### Echolocation training tasks

#### Real life tasks

Training tasks can be used to test participants echolocation skills regarding size discrimination, distance estimations, orientation and texture judgements. A good example of such task is outlined in Thaler et al. (2014b).

This task is ideally carried out in a soundproofed room, lined with foam wedges to reduce echoes from walls. This version requires participants to discriminate the size of two stimuli, but can easily be manipulated to test orientation, material etc by adding different stimuli to the apparatus. Stimuli are fixed to a metal frame with two front facing extensions to which objects can be hooked onto. A set of interchangeable flat discs of various diameters consisting of one large reference disc and five numbered comparison discs can be fixed onto the bars. Participants should be blindfolded and stood

33cm away from the metal frame, the height of the frame adjusted so that the midpoint of the two forward facing bars lines up with the participants ears. Participants should then be instructed to practice producing mouth clicks and get used to the environment through a set of practice trials.



Fig.1 Ekkel, M.R et al. (2016). Set up of task apparatus in an echolocation study [Jpg]. Experimental brain research. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5315722/figure/Fig1/?report=objectonly>

For each trial, participants should place their hands over their ears temporarily to ensure they do not hear which discs are being fixed to the stand. Once the stimuli are secured, the instructor can tap the participants shoulder to let them know they can uncover their ears and begin clicking. After 20 seconds participants are prompted to say whether they think the top or bottom disc is the reference disc. Once the trial is complete, the participant should receive feedback on their answer which will allow for them to improve over trials (Thaler et al., 2014).

Note that research has shown free head rotations during echolocation can help with distance discrimination when orientation needs to be determined or the environment is particularly complex (Wallmeier & Wiegrebe, 2014). While this particular task may not be overly complex, it would still be beneficial to encourage participants to move their heads while producing sound, imitating the methods of expert echolocators as closely as possible while learning. Head movement will also make it easier for participants to find the edges of the stimuli.

If participants improve in accuracy after a set of trials, their distance from the frame can be increased in increments of 33cm to increase task difficulty. Such method would allow for participants to progress with the training. Wearing a blindfold for an extended amount of time can become disorientating and an instructor should be in the room with the participant at all times. Before every training session, participants should be reminded that if they become uncomfortable at any time, they will be able to remove the blindfold and leave the room if necessary (Thaler et al., 2014).

### Computerised tasks

Other tasks that could be utilised for training purposes are computer based/ virtual. Beneficially, this task can be completed in more locations provided with quiet room with suitable headphones. An example of a virtual echolocation training task is used in Dodsworth et al (2020). Virtual mazes were constructed using sounds previously recorded with physical simple mazes. The sounds were recorded

in an echo dampened foam wedge lined room, a speaker fixed to a manakin played click sounds from the mouth area and returning echoes recorded with microphones in the manakins ears. From this, six virtual mazes were created following T , U and stair shaped patterns with mirror versions (Dodsworth et al., 2020).

Participants were blindfolded and used the keyboard to navigate the mazes. The W, S, A and D keys move the participant forward, backwards, 45° counterclockwise and 45° clockwise respectively. Once a key was pressed and the participant moved, the click sound and echo sounds correspondent to that position/orientation in the maze was played. Should a participant hit a wall, an error tone would play.

Participants were required to reach the end of the maze within a particular time limit. This time limit can be altered to change the difficulty of the task and encourage progression. Participants completed trials in blocks of 30, which takes around 20 minutes to complete (Dodsworth et al., 2020).

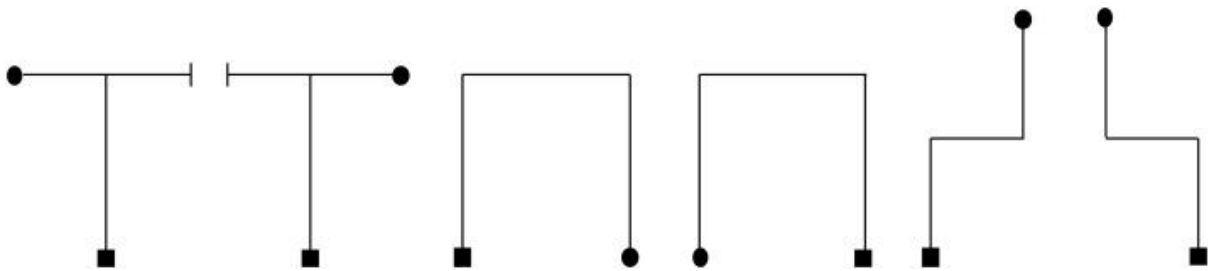


Fig.2 Dodsworth. C, et al. (2020).Line illustration of six virtual mazes used to test or train echolocation ability [Jpg]. ScienceDirect. <https://www.sciencedirect.com/science/article/pii/S0010027720300044>

## Use as training tasks

This research shows that sighted participants improved at navigating the virtual mazes after 10 weeks of practice, showing the task to be suitable for developing echolocation skills (Dodsworth et al., 2020).

Having both types of training tasks in use within the experimental group would allow for comparison of their effects on cognitive abilities. It would also allow observations of which is best for participant echolocation training in terms of ease and degree of improvement.

## Cognitive tests

**Attention** was measured using the auditory elevator subsets of the Test of Everyday Attention (TEA) in the language training study. These tests consisted of three tasks: the elevator task, elevator task with distraction and the elevator task with reversal. These measured auditory sustained attention, selective attention and attentional switching respectively. These tests were easily administered in a variety of settings and did not take long to complete- 20 minutes in total. In addition, there were three different versions of each task (A,B,C) making it suitable for a repeated measures design without practice effects (Bak et al., 2016 ; Robertson et al., 1996).

Each subtest involves:

Elevator task- participants are asked to imagine they are in an elevator with a broken button display. In order to determine which floor they are at, they need to count tones presented at irregular intervals. This task has 7 trials.

Elevator task with distraction- Participants repeat the elevator task but are required to count only low-pitched tones and ignore high-pitched tones that are played irregularly alongside. This task has 10 trials.

Elevator task with reversal- participants are required to count middle pitch tones while also listening to high and low pitch tone. As well as counting middle tones a high tone indicates that the count should be increased by a tone, while a low tone indicates the count should be decreased by a tone. This task has 10 trials.

Because this task is auditory it is also more accessible to those with no or impaired vision (Robertson et al., 1996).

**Working memory**- the effects of online ‘brain training’ via Lumosity on working memory was measured by a *visual/spatial n-back task*. This version of the n-back task requires participants to remember the location of a grey circle in one of 8 peripheral locations on a screen. If the circle appeared in the same location it had ‘n’ times ago, participants had to press the spacebar. N changed between 0, 1, 2 and 3 to increase difficulty. Response accuracy was measured by number correct and reaction time. (Kable et al., 2017).

N-back tasks can be adapted into an auditory format making it an ideal method for testing working memory in relation to echolocation training. An example of this was used in Monk et al (2011) developed as an application named the n-backer. Spoken numbers were used as stimuli and read to participants by the computer system. Participants verbally responded only on correct stimuli; their response was picked up by the system. The settings of this application could also be changed to determine the value of ‘n’. Response accuracy was measured by number of correct responses out of 48 trials (Monk et al., 2011).

Working memory can also be tested via *word or digit span*. Janus et al (2016) measured working memory capacity with a forward and backward word span test. Words were read aloud by the experimenter in sequence, increasing by one each time until the list increased to eight. Participants had to recall the sequence in forwards and backwards fashion depending on condition. Scores are calculated by number of words correctly recalled. The auditory format of this test also makes it appropriate for testing working memory and echolocation (Janus et al., 2016).

**Spatial cognition** may additionally have a role in echolocation. To assess spatial abilities non-visually, Ekkel et al (2016) used a set up of a round circular platform, to which six 3D differently shaped objects could be fixed in various locations. Participants were blindfolded and assessed the location of the shapes by touching the platform. After 60 seconds, the experimenter removed at least one object from the platform and turned it 90 degrees. Participants were then tasked with placing the object(s) back onto the platform while still blindfolded. The placement was counted as successful if it was in the original location or in a location adjacent, if placement was incorrect for more than two trials, the test was terminated. Scores were calculated out of 12, the maximum possible number of trials. In this particular study, researchers emphasise the need to research spatial cognition that is affected by ‘real-life’ echolocation tasks involving active navigation, like that in the computer-based task outlined above (Ekkel et al., 2016 ; Dodsworth et al., 2020).

**Reaction time** can be measured in conjunction with other tests, for example reaction time during n-back tasks. Alternatively, it can be measured as its own function/ability using a ruler drop test (Del Rossi et al., 2014).

## Time scales

The primarily discussed research involving cognitive improvement varies in training time between papers. Amount of time participants spent learning the skill, such as Gaelic language, ranged from around 1 hour per week to almost 5 hours a week.

Taking an average, it would seem appropriate to implement echolocation training at around 2-3 hours a week to allow for participants to improve.

## Discussion

### Benefits of cognitive training interventions

Alongside the development of medicine, memory impairment caused by illnesses such as dementia may be tackled with non-biological methods such as cognitive training. Cognitive training used in conjunction with cholinergic drugs shows to be promising with reducing milder memory loss (Requena et al., 2004 ; Mimura & Komatsu, 2007). More recent research indicates that computerized cognitive training (CCT) is an efficient method for improving global cognition in older adults, including working memory and attention (Hill et al., 2017).

Research is repeatedly calling out for more investigation into brain diseases such as dementia due to the rapidly increasing prevalence in an aging population. Data on which interventions are most suitable is needed (Manzine & Pavarini, 2009 ; Liang & Carlson, 2020). A common characteristic of illnesses like dementia is decline in language (Bayles, 1982). This difficulty with language leads to many cognitive interventions being unsuitable for individuals with language impairments to engage with. As previously mentioned, echolocation does not require language use.

Regarding these findings, it would seem highly beneficial to investigate whether echolocation training in both physical and computerized form can improve cognitive abilities in a similar fashion. Outcomes of this research potentially have real-life, beneficial, practical applications to fighting cognitive decline in older adults and those with degenerative brain diseases.

### Implications for future research

The promising outcomes of study into training new skills and improving cognitive abilities provide insight into how we can fight cognitive decline in ways that cannot be achieved by some commercial programmes that claim to be 'brain training' (Kable et al., 2017).

Echolocation has proven to be relatively easy to learn, is accessible to those with impaired vision and/or language and requires few materials to use. Additionally, it has been shown how echolocation can be trained both in real life surroundings and computerised settings (Thaler et al., 2014 ; Dodsworth et al., 2020). Many of the cognitive tests administered in language, music and brain training research would also be suitable for testing alongside echolocation training to observe any improvements. Lots of these tests do not require vision or can be adapted into auditory formats for suitability to a wider range of participants. Additionally, the majority of these tests have, or can be adapted to have, multiple versions allowing for re-testing without any practice effects. These available tasks and tests would allow for research following a test-retest format with echolocation training in between.

Age is an important factor both in terms of learning echolocation and cognitive abilities in terms of plasticity and changes to cognition over the lifespan (Teng et al., 2011). Future research could also be used to investigate possible age differences in ability to learn echolocation and age differences in any consequential changes to cognition.

Considering recent suggestion that CCT efficiently improves global cognition in older adults experiencing mental decline, there is a need for study involving virtual echolocation training tasks. If echolocation training is correlated with an improvement in cognitive abilities, a computerised version of training would be ideal as a candidate for a non-biological intervention for degenerative brain diseases (Hill et al., 2017).

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