Cognitive Abilities in Human Echolocation

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Abstract

The human ability to echolocate differs between individuals. Blind perform significantly better than sighted. There is very limited research on psychological factors underlying this ability. This study is based on earlier research by Schenkman and Nilsson (2010). The research questions in the present study were whether blind individuals perform better than sighted on general cognitive tasks, if people who perform well on echolocation tasks, also perform well on general cognitive tasks, and is there a correlation between performance on echolocation tasks and general cognitive tasks? Participants were 8 blind (5 female and 3 men) and 4 sighted (3 female and 1 male). Range of age was 36 – 65 years. Cognitive tests used were Digit Span, California Verbal Learning Test and an auditory reaction time test. The blind performed significantly better than the sighted on learning over trials. There was significant difference in focused attention, working memory and learning over trials between individuals who performed well on echolocation tasks and the rest of the sample. There was a positive correlation between learning over trials and individuals' ability to echolocate. The conclusion of this report is that blind individuals perform better on learning over trials and that people who perform well on echolocation tasks are superior in the cognitive abilities focused attention, working memory and learning over trials.
Cognitive Abilities in Human Echolocation

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Echolocation is often associated with mammals like bats, dolphins and whales. These animals all hold the ability to echolocate with great precision, and echolocation is used for orientation and hunting. Earlier research has found that blind individuals can use echolocation as a primary source for navigation when they move around in unfamiliar environments (Schwitzgebel & Gordon, 2000). They also use echolocation for object detection but also to gain general information about their environment (Schenkman, 1985). Echolocation, as it will be defined in this report, is the ability to detect the reflective and reverberant characteristics of an object or an environment using sound generated in the area.

Echolocation by Animals

Bats use both auditory information and visual information for navigation, obstacle avoidance, altitude control and for pursuit of food and water. They also use their memory and what has been termed perceptual cross-checking to get the systems to co-operate (Schenkman, 1985). For example, the Bat Eptesicus Nilssonii normally uses echolocation for hunting, but when it hunts in areas that has a lot of distracters (e.g. high grass) it instead uses vision, thus the two systems complements each other (Rydell & Eklöf, 2003).

Human Echolocation

The phenomenon facial vision was first described by the French philosopher Diderot in the 1770’s. He suggested that blind individuals were able to sense the presence of objects and that the sensation was a result from activation of receptors in the skin (Worchel, Mauney, & Andrew, 1950). Dallenbach and co-workers later showed that facial vision actually was constituted by echoes. The stimulation had to be aural to
produce the sensation (Supa, Cotzin, & Dallenbach, 1944). In studies where participants had distracting ambient noise (60-70 dB) while trying to echolocate, the performance was reduced. On trials when participants wore earplugs producing a hearing loss (30-50 dB) performance dropped dramatically (Stoffregen & Pittenger, 1995). This indicates the important role of a functional hearing ability. There is an important difference between human and animal echolocation. Animals mostly use sounds emitted from themselves and the sound reflections of objects. A blind person uses both sounds emitted from themselves, for example their voice, but they also use mechanical sounds that for example arises from the bottom of their shoes, a cane or a clicker (a device that emits a sharp clicking sound when it is applied) (Schenkman & Nilsson, 2010).

Some of the earlier research on human echolocation was carried out by Dallenbach in the 1940’s and 1950’s. In these studies the participants were instructed to walk toward an object, and when they felt the object’s presence they were suppose to stop. After that they again started walking against the object and they were supposed to stop when they were as close to the object without causing a collision. In this exercise the object was a masonite board. In some of the trials the board was absent. The participants were forbidden to use their voice, but they were allowed to create as much mechanical noise as they wanted (Supa et al, 1944; Ammons, Worche, & Dallenbach, 1953). Supa et al, (1944) conducted the same kind of experiment but they did it indoors. In the experiment the participants either wore shoes or just stockings. The participants who wore shoes were able to detect objects at distances of up to 5 m, in the latter, the maximum distance was about 3 meters. Blind participants performed better.

Kellogg (1962) also conducted a study in echolocation with both sighted and blind participants. The participants were instructed to make any sound that they wanted. The participants created both vocal sounds (e.g., clicking whit their tongue, talking and whistle) and created manual sounds (e.g., snapping their fingers). The sighted participants performed poorly while the blind participants could discriminate between objects distance, size and texture (Stoffregen & Pittenger, 1995).
Schenkman and Nilsson (2010) conducted a study with 10 sighted and 10 blind participants. The participants were presented with two sounds, one with a reflecting object and one without, after that the subjects were to specify which of the two sounds that contained the reflecting object. In the study they used a 2-alternative-forced-choice method. All participants performed well when the object was 2 m or less from the participants. However, also in this study it was shown that the blind participants could detect objects further away than the sighted were capable of (Schenkman & Nilsson, 2010). The present study is based on the earlier work of Schenkman and Nilsson (2010). The same participants were used, as well as the data showing their performance on echolocation tasks.

Factors for human echolocation
There have been various psychophysical mechanisms proposed for human echolocation. Some of the earlier researches have focused on loudness and repetition pitch in the sound source. This phenomenon can be explained by a direct sound that reflects against an object. The direct and the reflected sound are combined but with a separation in time which is proportioned to the objects distance (Schenkman & Nilsson, 2010).

Learning and memory capacity are important factors for human echolocation (Schenkman, 1985). Influence of these two factors may partly explain the high individual difference between people who is visually impaired and their ability to echolocate. Rice (1969) showed that people with an early onset of blindness are superior to people who had a late onset of blindness and seeing subjects when it came to auditory localization and that they performed consistently superior when it came to tactile immediately memory.

Juurmaa (1969) showed that there was a positive correlation between an early onset of blindness, how young the participants were, and their ability to use echolocation for obstacle avoidance. It was also shown that blind and seeing participants could train their ability to avoid collusions fairly rapidly, however the
ability to estimate the size of obstacles took much longer time for the seeing (Juurmaa, 1969).

Perceptual Learning

Perceptual learning is a process that involves changes to an organism’s perceptual systems that improves its ability to respond to its surrounding. Perceptual learning is not achieved simply by one process. Cognitive scientist have distinguished between training mechanisms that are driven by some kind of feedback and those that require no feedback, the mechanisms with no feedback operates only with the information that is naturally in the structure of the stimuli (Goldstone, 1998).

The ecological approach to visual space perception was developed by J.J Gibson. The major claims of his theory is that perception of the environment is direct and directly represented by images or representations; that no memory, schemata or other cognitive structures contributes to perception. The theory states that the features of the environment are directly perceived and that it includes meaningful information reflecting an animal’s interests and utilities and that computation is not involved in perceiving (Bruce, Green, & Georgeson, 1996; Knapp & Roberson, 1986).

One way in which perception becomes adapted to tasks and environment is by increasing the attention paid (attentional weighting) to the features that are of importance to the “viewer” or trying to decrease attention of features and dimensions that are irrelevant. Recent evidence has indicated that sound categories and categorical perception generally come from learning. For example, expert musicians show a pronounced categorical perception effect for relative pitch differences. This indicates that training was contributing to the awareness boundaries between semitones (Goldstone, 1998). It could be that individuals who perform with good accuracy regarding echolocation have trained their ability to focus the attention on the difference in repetition pitch while conducting echolocation. This could indicate that attention is of importance for the individuals.
Another way that perception can adapt to the environment is by directly imprinting to it (stimulus imprinting). The receptors are created, form is shaped by the stimulus when imprinting occurs, and it can be shaped either to the whole stimulus or only features of it. Receptors are developed for repeated stimuli, and these receptors increase the speed, accuracy and fluency with which the stimuli are processed (Goldstone, 1998).

One mechanism of perceptual learning is differentiation, this claims that percepts that originally were psychologically fused together, become increasingly separated from each other over time. Once the percepts are differentiated from each other discrimination can be made between the percepts that originally seemed impossible to distinguish. The learning of how to differentiate between objects is typically accelerated by learning which objects are associated with different labels or responses (Goldstone, 1988). Monkeys trained for several weeks to discriminate small differences in frequency for tonal stimuli exhibit an improvement in performance and they developed a larger cortical representation for the specific frequency of the stimulus presented (Recanzone, Schreiner, & Merzenich, 1993).

Unitization is a perceptual learning mechanism that involves the construction of single functional units that can be triggered when a complex configuration arises. Using unitization means that a task that originally required several parts to detect can be accomplished by detecting only a single part (Goldstone, 1988).

Regarding earlier research it is clear that blind individuals differ from sighted when it comes to echolocation (Stoffregen & Pittenger, 1995; Schenkman & Nilsson, 2010). Earlier research has mainly focused on psychophysical mechanisms regarding echolocation. Perceptual learning may in some way be able to explain why people differ in the ability to echolocate. People with an early onset of blindness have shown a positive correlation to the ability to echolocate (Juurmaa, 1969; Rice, 1969). Individuals that have been blind for a longer time may through this time advantage have learned to control the mechanisms in perceptual learning and this may have contributed in a positive way to their ability to echolocate. Even with this in mind there is no knowledge of the underlying mechanisms in perceptual learning in
echolocation. The suggested role of cognitive factors underlying perceptual learning (Rice, 1969; Schenkman, 1985) motivates further investigation of such factors. This leads to the research questions of the present study;

1. Do blind individuals perform better than sighted on general cognitive tasks: (a) focused attention (b) working memory (c) learning and (d) general mental ability?

2. Do people who perform well on echolocation tasks also perform well on general cognitive tasks: (a) focused attention (b) working memory (c) learning and (d) general mental ability?

3. Is there a correlation between performance on echolocation tasks and general cognitive tasks: (a) focused attention (b) working memory (c) learning and (d) general mental ability?
Method

Participants
All participants, 8 blind and 4 sighted, had participated in the study of Schenkman and Nilsson (2010), and were, or had been, employed at the Swedish Association of the Visually Impaired. The participants had also undergone a hearing test in the study by Schenkman and Nilsson. From the previous study by Schenkman and Nilsson, (2010) there was a 40% dropout of participants. The participants reported that some of the underlying reasons for the dropout were a notice of a major discharge at the workplace, some participants declined to participate because they thought the previous test had been mentally exhausting and some of the early participants had moved from the city. All participants got reimbursement with a gift certificate for 100 SEK.

Blind participants
Of the 8 blind participants 5 were female and 3 were male. They were between 36 and 65 years old. (mean = 55.9, std. = 10.1). All had very limited vision; at the most they had the ability to distinguish lightness shifts.

Sighted participants
The 4 sighted participants consisted of 3 females and 1 male. They were between 59 and 63 years of age. (Mean = 60.7, std. = 1.7). All participants reported that they had normal vision. They wore a blindfold while conducting the experiment. One participant mentioned a hearing disorder in both ears, and therefore wore a hearing aid while conducting the test.

Fisher’s exact test were conducted to see if there were any significant difference concerning gender and education between the populations. There were no significant difference for education (p = 0.424) or gender (p = 0.594). One-Way ANOVA were conducted for age to see if there were any significant age difference between the two populations. There was not a significant difference F (1,881) = 0,370, p >.005).
Material

This study was conducted in a sound studio at the Swedish Association of the Visually Impaired in Enskede. The room was soundproof. All material for the test was presented for the participants using a portable computer (Lenovo 3000 C100, OS: Windows XP) and the sounds were reproduced by headphones (K44 Headphones). For the reaction time test the participants used a keyboard with tactile reinforcement for the keys a, ö and the space key.

Conducted tests were Digit Span Forward (DSF), Digit Span Backward (DSB), the first part of California Verbal Learning Test (CVLT) and two tests that examined the participant’s reaction time; one for single stimuli (RS) and one for two stimuli (RT). All above mentioned test except RS and RT had prior been recorded in a digital sound editor (Audacity 1.2.6). Elocutionist was a 25 year old man with a dialect that is representative for northern Sweden. All information was presented in Swedish. After each sequence there was a manipulated signal that was presented 0.5 s after the material. The function of the signal was to indicate the participants that they should reproduce what they had heard.

*Digit Span Forward*

DSF is a verbal test that measures the individual’s focused attention (Groth-Marnat, 2003; Lezak, Howieson, & Loring, 2004). In this test the participants are presented with a sequence of numbers, after implemented sequence the participants should reproduce the sequence exactly as it had been presented. The test started with a sequence of 3 digits that were read at a speed of 1 digit per second. When a sequence was correctly reproduced the next longer sequence was presented. The test continued until the participant failed to reproduce the correct sequence twice on the same length or when the longest sequence was reproduced correctly (Sequence of 8 digits; Lezak et al, 2004).
**Digit Span Backward**

DSB is a verbal test that measures the individual’s working memory (Groth-Marnat, 2003). Baddeley and Hitch (1974) originally divided working memory into three components; the visuospatial sketchpad, the phonological loop and the central executive and later included episodic buffer (Baddeley, 2000). The central executive is assumed to be an attention-controlling system, it is responsible for the control and regulation of cognitive processes. The visuospatial sketchpad manipulates visuospatial components, and the phonological loop stores and rehearses speech-based information and is assumed to hold digit sequences for immediate recall (Baddeley & Hitch, 1974). The episodic buffer is assumed to be a mechanism that is capable of combining a range of different storage dimensions, the store is temporary and has limited capacity (Baddeley, 2000). Regarding this, DSB would be managed primarily by the phonological loop, but there may be involvement of the central executive (Ostrosky-Solis & Lozano, 2006). DSB involves two functions; the participant must hold the digits combination in memory at the same time as they must convert the series. This method is reliable for an age group up to 70 years (Lezak et al, 2004).

The implementation is the same as in DSF, but instead of repeating the exact sequence the participants should reproduce the sequence backwards. This test continued until the participant failed to reproduce the same length of sequence twice or they had reproduced the longest sequence correctly (sequence of 7 digits; Lezak et al, 2004).

**California Verbal Learning Test**

CVLT is a clinical test that is designed to measure how much a subject learns, but also to show how they learned it. The test examines free and cued recall, serial position effects, semantic clustering, intrusion, interference and recognition (Elwood, 1995).
CVLT is composed of 16 shopping items from four categories, tools, clothes, vegetables and spices. The shopping list was read for the participants in 1s intervals over five sequential trials. The subject’s task was to freely recall as many items as possible after each trial (Norman, Evans, Miller, & Heaton, 2000; Delis, Kramer, Kaplan, & Ober, 1987). The words used for this test were translated from the original to Swedish (Delis et al., 1987). This study focuses on the analysis of overall learning, measured by the total word recalled for trials 1-5, as well as comparison involving trial 1 versus trial 5.

Reaction Time
In a study using a sample of 900 people it was shown that simple reaction time had a correlation of -.31 with the Alice Heim 4. With four-choice reaction time it correlated -.49. The Alice Heim 4 is a test that measures the individual’s general mental ability (Deary, Der, & Ford, 2001).

The reaction time test with a single stimulus was conducted with custom designed software in which the subjects used their dominant hand to affect a keyboard, which affected the software. The stimuli presented were tones presented randomly between 2300 and 4000 ms, this to avoid anticipatory effects. Each subject was presented with the stimulus 24 times.

The reaction time test with two stimuli used the same software as the test with the single stimuli. In this test the subjects were presented with two stimuli, the sound of shattered glass and a car horn honking. The participant was to associate the sounds to either the a or ö key. They first did a practice run 10 times so that they would learn the relationship between the sound and the key. In the practice run there was a voice reporting if they pressed the correct key or not. After the practice run they did it 24 times without reinforcement. The stimuli were presented randomly between 2.4 and 4 s.
Procedure

Each participant was tested individually, sitting upright on a chair with both feet on the floor. The participant was verbally instructed following a manual (Appendix 1). The order of the test was the same for all participants starting with DSF followed by DSB, CVLT, RS and ending with RT. Before every test, verbal information was given (Appendix 2). The total time for the test was estimated to 1 hour, the participants was informed that they had the possibility to take a break, if they at any time felt exhausted. A speech dictation device was used for recording of the verbal answers.

Statistical Analysis

Statistical analyses were conducted with SPSS 18.0. The significance level for all conducted tests was 0.05.

Data was analysed by comparing the groups blind and sighted, a secondary analyse was conducted for the 4 individuals that had a mean score on the echolocation task of > 85.0 % correct for all conditions up to 200 cm. Results > 200 cm was not used because most listeners, sighted as well as blind, performed mostly at chance (Schenkman & Nilsson, 2010). These individuals represent one group and they were compared with the rest of the participants, both blind and sighted.

Every test except the reaction time tests were calculated with the individual’s raw score. The individual representation regarding the reaction time tests was represented by the mean value for each test. Mean value calculation was conducted for all tests. Univariate analysis of variance was conducted to see the groups score and to see if there is any significant difference between the groups regarding each test. Correlation analysis was conducted using Pearson Correlation coefficients to see if there was any correlation between the test scores and the person’s ability to echolocate.
Results

Blind (B) versus Sighted (S)

Results showing mean (Std.) and ANOVAs values for the groups (B) and (S) are presented in Table 1. There was a significant difference between the blind and the sighted groups on the CVLT trial 1 and for the CVLT total word recall but not for DSF, DSB, CVLT trial 5 or RS. A small tendency was seen for the RT.

Table 1. Mean (Std.) scores for blind (B) and sighted (S) groups, and results on ANOVAs

<table>
<thead>
<tr>
<th>Test</th>
<th>B</th>
<th>S</th>
<th>F- and p-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSF</td>
<td>6.38 (1,589)</td>
<td>5.25 (0,500)</td>
<td>F= 1,812, p = 0.208</td>
</tr>
<tr>
<td>DSB</td>
<td>5.13 (1,246)</td>
<td>4.25 (0,500)</td>
<td>F= 1,756, p = 0.215</td>
</tr>
<tr>
<td>CVLT_Trial_1</td>
<td>9.13 (2,872)</td>
<td>5.25 (2,872)</td>
<td>F= 10.105, p = 0.010</td>
</tr>
<tr>
<td>CVLT_Trial_5</td>
<td>14.00 (2,268)</td>
<td>12.00 (2.000)</td>
<td>F= 2.222, p = 0.167</td>
</tr>
<tr>
<td>CVLT_Tot</td>
<td>60.88 (8,686)</td>
<td>44.50 (5,447)</td>
<td>F= 11.724, p = 0.007</td>
</tr>
<tr>
<td>RS</td>
<td>252,290 (33,816)</td>
<td>270,615 (20,846)</td>
<td>F= 0.962, p = 0.350</td>
</tr>
<tr>
<td>RT</td>
<td>524,450 (87,146)</td>
<td>625.00 (81,211)</td>
<td>F= 3.711, p = 0.083</td>
</tr>
</tbody>
</table>
High performance (HP) on echolocation versus remaining sample (RE)
Results showing mean (Std.) and ANOVAs values for the groups (HP) and (RE) are presented in Table 2. The results show that the HP performed significantly better than RE on DSF, DSB, CVLT total word recall, and RT and showed a tendency of better performance also on CVLT trial 1 and trial 5. There was not a significant difference on RS.

Table 2. Mean (Std.) scores for high performance (HP) on echolocation and population (RE) groups, and results on ANOVAs

<table>
<thead>
<tr>
<th>Test</th>
<th>HP</th>
<th>P</th>
<th>F- and p-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSF</td>
<td>7.25 (0.957)</td>
<td>5.38 (1,188)</td>
<td>F= 7.426, p = 0.021</td>
</tr>
<tr>
<td>DSB</td>
<td>6.00 (1.155)</td>
<td>4.25 (0.463)</td>
<td>F= 14.848, p = 0.003</td>
</tr>
<tr>
<td>CVLT_Trial_1</td>
<td>9.75 (1,500)</td>
<td>6.88 (2,696)</td>
<td>F= 3.825, p = 0.079</td>
</tr>
<tr>
<td>CVLT_Trial_5</td>
<td>15.00 (0.816)</td>
<td>12.50 (2,390)</td>
<td>F= 3.968, p = 0.074</td>
</tr>
<tr>
<td>CVLT_Tot</td>
<td>67.75 (3.775)</td>
<td>49.25 (7,265)</td>
<td>F=22.139, p = 0.001</td>
</tr>
<tr>
<td>RS</td>
<td>249.902 (39,698)</td>
<td>262.646 (26,840)</td>
<td>F= 0.443, p = 0.521</td>
</tr>
<tr>
<td>RT</td>
<td>477.170 (35,014)</td>
<td>598.464 (90,320)</td>
<td>F= 6.455, p = 0.029</td>
</tr>
</tbody>
</table>
Correlation-analysis between ability to echolocate and cognitive tests

Results showing Pearson correlation coefficient and p-values (2-tailed) between the ability to echolocate and the cognitive tests are shown in Table 3. There was a significant positive correlation between the ability to echolocate and CVLT trial 1 and CVLT total word recall, but not for DSF, DSB, CVLT trial 5, RS or RT.

Table 3. *Pearson Coefficient scores and p-value for correlation between echolocation ability and tests*

<table>
<thead>
<tr>
<th>Echo</th>
<th>Pearson Coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSF</td>
<td>0.173</td>
<td>0.59</td>
</tr>
<tr>
<td>DSB</td>
<td>0.369</td>
<td>0.238</td>
</tr>
<tr>
<td>CVLT_1</td>
<td>0.578</td>
<td>0.049</td>
</tr>
<tr>
<td>CVLT_5</td>
<td>0.431</td>
<td>0.162</td>
</tr>
<tr>
<td>CVLT_TOT</td>
<td>0.599</td>
<td>0.04</td>
</tr>
<tr>
<td>RS</td>
<td>-0.089</td>
<td>0.784</td>
</tr>
<tr>
<td>RT</td>
<td>-0.398</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Discussion

The aim of the study was to relate echolocation data for human observers to cognitive functions, to see if any of these psychological functions could help explain why different individuals perform differently on echolocation tasks.

The main results from this study show that (1) blind individuals perform significantly better than sighted on learning (CVLT trial 1 and CVLT total word recall), but not on focused attention (DSF), working memory (DSB) or general mental ability (RS, RT). (2) It also showed that the 4 individuals who performed of > 85.0 % correct on the echolocation task were significantly better than the rest of the subjects concerning focused attention (DSF), working memory (DSB), learning over trials (CVLT). The results on (RT) might indicate a higher general mental ability, thus are these result inconclusive regarding that there was not a significant difference on (RS). There was not a significant difference concerning CVLT trial 1 or 5. (3) There was a significant correlation between performance on echolocation task and CVLT 1 and CVLT total word recall, but not for DSF, DSB, CVLT trial 5, RS or RT.

The results from this study strengthen earlier research regarding learning, individuals who perform well on echolocation tasks also perform well on learning task over trial (CVLT) the positive correlation also strengthen these findings. This proves that learning is an important factor for echolocation (Schenkman, 1985), (Rice, 1969).

Rice (1969) proposed that memory should be of importance for echolocation. In a tactile immediate memory task the results favored the blind. The result from this study broaden the knowledge about which memory functions that is of importance for echolocation, thru the auditiv working memory test, it is shown that the (HP) is significantly better than (P), this indicates that working memory might play an important role for echolocation.

A study by Kujala (Kujala, Lehtokoski, Alho, Kekoni, & Näätänen, 1997) showed that blind individuals react significantly faster than sighted on auditiv reaction tests.
The results from this report are not in line with those results, as the blind individuals did react faster, but there was not a significant difference.

Deary et al. (2001) had a correlation of -.31 for simple reaction and -.49 with the Alice Heim 4. The significant result on RT for the HP indicates that there could be a difference in general mental ability between HP and RE, but the results on RS makes these result inconclusive.

This report used a strongly restricted sample size, but despite the small sample significant differences were discovered which might indicate that the effects are rather strong. The participants age are also rather high, mean age for both groups are >55 years which could make it hard to generalize the data for younger populations.

There were no specific measures regarding the motivation of the subjects, there is possible that the blind subjects would be more motivated than the sighted to perform well. Regarding the test was related to echolocation and previous results (that blind individuals perform better than sighted on echolocation tasks) from the study by Schenkman and Nilsson (2010) had been advised. An indication that the subjects lack in motivation is, if the results from DSF is lower than the results from DSB (Lezak, et al., 2004), that was not the case in any of the participants which might indicate that they all were motivated.

This study shows that (HP) and (RE) significantly differ in many cognitive abilities, it would be of interest to conduct further cognitive research, to see the underlying reason why the individuals (HP) differ from the normal population concerning these specific abilities. It would also be of interest to see the neural activation under a FMRI scanning while the participant is conducting a task in echolocation, this could give a bigger picture of which areas in the brain that is activated, and help further research to evaluate what the differences are. Further research should also look into whether training of these specific cognitive abilities also improve the individuals ability to echolocate.

Research of a larger sample would be needed to see if the results shown in this study also would be representative for a broader age group and a larger sample of individuals.
References


Appendix 1

Participant information

Detta är en forskningsstudie som syftar till att öka förståelsen till hur mänsklig ekolokalisation förhåller sig till andra förmågor som människan har. Denna studie ska undersöka sambanden mellan ekolokalisation och olika kognitiva förmågor.

Studiens upplägg är att ni kommer genomgå 5 olika hörselbaserade uppgifter, den totala testtiden är beräknad till 60 minuter. Under varje test kommer hörlurar att användas för att presentera ljuden. (Seende. Ni kommer under försöket bära ögonbindel för att undvika visuella distraktorer.) Jag vill att ni under testet ska sitta bekvämt i stolen, ryggen ska vara placerad mot ryggstödet och ni ska ha båda fotterna i marken.

Mer ingående information gällande testets syfte kommer ges efter att samtliga test är genomförda.

Under testet kommer en diktafon att användas för att underlätta registrering av era svar, ljudfilerna kommer endast använda för denna studie och ljudfilerna kommer raderas så fort all data är överförd till dator.

Inför varje test kommer ni få tydlig information om hur det enskilda testet kommer att gå till väga, samt vad som förväntas från er sida.

Mellan varje deltest kommer det finnas möjlighet att ta en kortare paus. Om ni under testet känner att ni börjar bli trötta kan ni säga till i någon av pauserna så får ni ta en extra bensträckare.

Denna studie är helt frivillig. Oavsett tidpunkt kan ni välja att avbryta ert deltagande, ni behöver inte ge någon anledning varför ni vill avbryta och detta kommer inte på något vis få negativa konsekvenser.

Samtliga data gällande personlig information kommer att behandlas konfidentiellt och endast användas i forskningssyfte.

Innan testen påbörjas kommer jag att ta era personuppgifter.

Några frågor innan vi börjar?
Appendix 2.

Test information

**Digit Forward**


Om du exempelvis hör siffrorna 1-2-3-pip. Vad ska du då återge?

**Digit Backward**


**CVLT**

Försök 1.


Försök 2.

Nu kommer shopping listan upprepas igen. Jag vill att du ska återge så många objekt som du kan i valfri ordning. Var noga med att också återge de artiklar på listan som du berättade för mig första gången. Är du beredd?

Försök 3-5.
Nu kommer shopping listan upprepas igen. Jag vill att du ska återge så många objekt som du kan i valfri ordning, inklusive de artiklar som du kanske redan har berättat för mig.

_Reaktion - Snabbhet_

_Reaktion – Flerval._
Träning

_Snabbval_
Nu när du har lärt dig sambandet mellan respektive ljud och tangent ska du göra denna uppgift utan återkoppling dvs. Ingen röst kommer säga om du väljer rätt eller fel tangent för respektive ljud.