Lateralization effects of auditory white noise on verbal and visuo-spatial memory performance

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Abstract

Research has shown that white noise may have a positive impact on cognitive performance, among individuals who exhibit a change in their dopaminergic levels, through the phenomenon of stochastic resonance. The aim of this study was to examine lateralization effects of white noise exposure during a verbal memory task and a visuo-spatial working memory task within two age groups. The hypothesis was to find an age and ear interaction and the results supports the hypothesis to a certain extent. Findings are in line with the theory that noise exposure has an impact on cognitive performance.

Background

The negative effects of disturbing noise on cognitive processing has been widely reported (Broadbent, 1958). Nevertheless, a specific amount of noise has been observed to enhance performance in certain groups of individuals, such as children with attention-deficit/hyperactivity disorder (ADHD) (Söderlund et al., 2007). Söderlund, Sikström, Loftesnes and Sonuga-Barke (2010) have shown that the amount of noise needed is dependent upon the individual and that it differs considerably between groups. Inattentive school children in particular seemed to improve in a verbal free recall task, when exposed to background white noise during memory encoding. It has been hypothesized that this is linked to the dopaminergic (DA) levels of the neural system through the phenomenon of stochastic resonance (SR) (Sikström & Söderlund, 2007).

SR occurs in natural, as well as man-made nonlinear systems. An example of a natural nonlinear system is the human nervous system. When adding noise to a signal that is just below the detection threshold, the noise and signal together elicits an action potential through the phenomenon of SR. SR enhances communication between neurons and thus improves perception (Moss, Ward & Sannita, 2004).

Since it has been observed that individuals with deficits in the DA system, such as the hypo-dopaminergic state in ADHD (Solanto, 2002) and the lower levels of DA in older people (Erixon-Lindroth, Farde, Wahlin, Sovago, Halldin & Backman, 2005) benefit from noise during certain activities (Li, von Oertzen & Lindenerber, 2006), it has been suggested that SR helps to somewhat compensate for low DA levels (Sikström & Söderlund, 2007). There is also evidence of cross-modal effects related to SR, such as improved visual detection, when adding auditory white noise (Manjarrez, Mendez, Martinez, Flores & Mirasso, 2007).

Earlier research has shown that DA is an important neurotransmitter involved in cognitive functioning. The ability of attention and control of cognitive functions varies among groups. For instance, autopsy studies have indicated losses of DA receptor densities from early to later adulthood, the rate of decline being estimated to just below 10% per decade. Thus, these findings show that age loss in DA effects cognitive performance (Bäckman, Nyberg, Lindenberger, Li & Farde, 2006).

The human brain has an asymmetrical organisation of functions between the two hemispheres, this is called lateralization. For right handed individuals, this means that the verbal episodic memory normally is lateralized and processed in the left hemisphere, while the visuo-spatial memory commonly is lateralized and processed in the right hemisphere (Kolb & Whishaw, 2009). The auditory and the visual system are contralaterally connected between the hemispheres. Dichotic listening tests have shown that right handed participants are more likely to report verbal information that is presented to the contralateral right ear, indicating that the pathway from the right ear to the left (verbal) hemisphere, has preferred...
access (Hugdahl & Davidson, 2003). A study by Söderlund, Marklund and Lacerda (2009) describe noise effects as cross-modal, showing that exposure of auditory noise also has an effect on visuo-spatial memory tasks, normally lateralized to the right hemisphere.

Hence, it is now of interest to further explore the impact of auditory noise on non-clinical groups during cognitive tasks.

The aim of this study is to partly replicate two earlier studies (Ekstrand, Johansson, Lindau, Nordberg, Syrjäkylä & Söderlund, 2011 and Nilsson, Persson, Petersson, Safa & Sjölin, 2011) where the intention was to examine lateralization effects of auditory noise during verbal memory tasks (word recall) and visuo-spatial memory tasks. An effect of noise and age was observed – the older participants improved their performance when receiving noise contralaterally to task-specific hemisphere. Since the categorization of age in these former studies was conceived as quite arbitrary, a replication is necessary to attest the findings. Our hypothesis is that the performance of the older group will benefit from noise in the right ear during the word recall task, and from noise in the left ear during the visuo-spatial memory task.

Method

Participants

A total of 24 subjects chosen from a convenience sample participated in the study. Subjects were divided into two equal numbered groups based on their age, 20-31 years (N=12 M=26,5 SD=3,1) and 53-64 years (N=12 M=57,5 SD=3,3). In the younger group 9 were men and 3 were women. In the older group 8 were men and 4 were women. The mean number of educational years in the younger group was 15,6 years (SD=2,7) and 13,1 years (SD=3) in the older group.

All subjects had Swedish as their native language and were right handed. One subject had a slight hearing loss in left ear and the others (23 subjects) had normal hearing according to self report.

Material and apparatus

The word recall test was carried out using E-prime (version 1.2). 12 word lists, each containing 12 Swedish words of different orthographic length, were used. The letter size was 50 point, font Courier New, the words were presented white on black background, duration 3000 milliseconds for each word. Interstimulus intervals (i.e. pause between words) were 2000 milliseconds.

The visuo-spatial task was executed on a computer installed with Spanboard 2011 (Westerberg, Hirvikoski, Forssberg & Klingberg, 2004). Target was shown 2000 milliseconds with an interstimulus interval of 2000 milliseconds. The conditions of white noise were calibrated to 78 dBSPL (+1), according to the level shown to affect cognitive performance (Usher & Feingold, 2000). The headphones worn were Koss label, UR5 model and the sound pressure level meter used was Roline RO-1350.

Procedure

Both experiments were carried out at the Phonetics Laboratory at the Department of Linguistics, Stockholm University.

The participant information (age, gender and years of education) was filled in before starting the experiment. Each participant was given information about the procedure of the test situation in both written and verbal form. However, the participant was not informed about the purpose of the study.

Participants were seated at a computer screen, wearing headphones, in a silent room and started the test and each wordlist themselves.

Each noise condition was played three times. Words, wordlists and white noise were presented randomly. Between each wordlist subjects recalled the words verbally within a time limit of two minutes, two observers were present and noted the responses.

After the word recall test participants performed the visuo-spatial working memory test. The task was to repeat a pattern given by a red dot that appeared in a 4x4 chart. The number of appearances increased each turn until the subject did not succeed in giving a correct repetition in one of two trials. Every subject did the spanboard task four times, one for each noise condition.

The word recall test and the visuo-spatial working memory test lasted approximately 25 minutes each, with a 10 minute break in between. During the word recall task, first wordlist (noise presented in left ear), one participant wore incorrectly mounted headphones. These results were corrected in
SPSS by using the mean from the two correct lists in current condition.

**Design**

Independent variable was age – the between group manipulation (younger and older). The within individual manipulation was noise exposure (no noise (NN), noise left ear (NL), noise right ear (NR) and noise both ears (NB)). Dependent variable was number of correctly recalled words or correct clicks (spanboard).

**Results**

As can be seen in figure 1, results from the word recall test show that there was no main effect of noise. However, an overall interaction effect between noise and group appeared. A 4x2 ANOVA showed a significant interaction between noise and age ($F_{3, 20}=3.75$, $p=.035$).

Post hoc analyses were conducted to investigate between which conditions the effects appeared, pair wise comparisons were made between all conditions. When comparing NR with NB an interaction was found between noise and age. Performance in the younger group declined, while performance improved in the older group when presented noise in both ears ($F_{1, 22}=9.28$, $p=.006$). Another interaction was found between noise and age when comparing NN with NB. The older group improved their performance, while the younger group showed a decrease in performance ($F_{1, 22}=5.59$, $p=.027$). Finally, when comparing NL with NR an ear and age interaction was found where results indicated a trend ($F_{1, 22}=3.54$, $p=.073$), that noise exposure affected the age groups differently. NL had a negligible effect on performance in both groups, while they responded differently during NR – the younger group improved while the older group declined in performance.

In the visuo-spatial experiment, a 2-way ANOVA revealed a main effect of noise. This relation was curvilinear ($F_{3, 21}=3.32$, $p=.040$) (figure 2). Since no interaction between noise and age was found, groups were merged together.

![Figure 1. Results from word recall test. Number of correctly recalled words (y-axis) as a function of noise condition (x-axis) and group.](image1)

Post hoc analyses were conducted to investigate between which conditions the effects appeared, pair wise comparisons were made between all conditions. As can be seen in figure 2, performance was enhanced by noise exposure to the left ear ($t_{23}=-2.09$, $p=.047$) compared to no exposure of noise. When comparing noise exposure to the right ear and no noise exposure, results indicated a trend ($t_{23}=-1.73$, $p=.096$), that performance was enhanced by noise presented to the right ear.

As previously mentioned, one of the participants had a slight hearing loss on left ear. To make sure that this factor did not affect the results, all tests were run both omitting and including the subject’s data. No difference occurred, hence, the participant’s data was included.

**Discussion**

The aim of this study was to replicate two earlier studies (Ekstrand et al., 2011 and Nilsson et al., 2011). The hypothesis was that the performance in the older group would benefit from noise in the right ear during the verbal memory task (word recall), and from noise in left ear during the visuo-spatial memory task (spanboard).
In word recall, the findings (figure 1) supported the hypothesis to a certain extent; that the effect would appear in the right ear. However, the observed results were opposite to expected, as the performance of the older group declined, and the performance of the younger group was enhanced, when noise was presented in the right ear. Thus, results (figure 1) indicate that SR has a lateralized effect on verbal tasks, when noise is presented in right ear. An interesting aspect is that the expected effect appeared in both groups when noise was exposed to both ears. This may imply, that higher levels of noise are required to reach the hypothesized improvements among older adults, when performing cognitive tasks. A possible explanation to the enhanced performance in the older group while receiving a greater amount of noise, could be traced to age related loss of DA receptors, which among other things affects cognitive processing (Bäckman et al., 2006; Sikström et al., 2007).

In contrast to Ekstrand et al., (2011) the younger group was constantly performing at a higher level than the older group, in both word recall and the visuo-spatial tests. A reason for this could be that older adults are especially disadvantaged in situations when fast and efficient processing is needed (Bäckman et al., 2006). Another explanation could be the fact that the younger participants had a higher mean of educational years.

When grouping all participants together and comparing results from the two tests, different patterns could be observed. Results from the visuo-spatial experiment showed a curvilinear relationship (figure 2). In line with earlier research (Söderlund et al., 2009; Manjarrez et al., 2007) the findings from the visuo-spatial test showed that noise also has a cross-modal impact on cognitive performance.

Alongside studies by Moss et al. (2004), this study supports the theory that SR has an impact on cognitive performance, demonstrated in both the word recall task and the visuo-spatial memory task.

The homogeneity within the groups regarding attention and age, as well as the low number of participants might have affected the result of this study. The fact that subjects were chosen from a convenience sample and not randomly chosen, may also have influenced the result.

For future research it would be of interest to examine different levels of dBSPL and to further investigate the impact on performance when noise is presented in both ears. A replication with a larger sample would possibly give a more unequivocal indication of the hypothesized results.

References


