

# Anxiety-dependent spatial navigation strategies in virtual and real spaces

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## Introduction

The anxiety-related thigmotaxis strategy refers to a movement tactic to contact towards a larger object that serves as an orientation point from where the subject can find a safety background to begin route finding. This movement sequence towards a border of an enclosed place involves a tendency to avoid the inner zones and stay on the periphery is quantified by measuring the amount of path length spent in close contact with the wall. The Morris water maze (MWM) is a typical test for the hippocampal-based memory functions and goal-directed navigation (Morris 1981). The leading factor of exploration movement variation in the MWM is the thigmotaxis. During goal-directed exploration, the thigmotaxis inhibits the acquisition of the spatial relationships among the contextual cues, on the other hand serves as the definition of the border for an enclosed place and form of egocentric references to the proposed actions (Kállai et al 2005). This contradictory function of the anxiety-dependent thigmotaxis strategy reveals a basic neural organization conflict between the allocentric and egocentric reference frame-utilized spatial learning dynamics. A deeper insight is needed to identify the neuro-cognitive structure that involved in hold up this conflict.

The hippocampus (HP) is a key structure in supporting spatial memory, spatial navigation, and in the construction of a spatial map of the surrounding space in rodents and in humans. The HP is also involved in coping with stressful situations. Changes in the tissue structure of the HP due to

lesions or atrophy are associated with several neuropsychiatric disorders, nevertheless only a few studies examined the HP volume differences in healthy participants, so the healthy functioning of the HP-dependent spatial learning and its neuro-cognitive basis in humans remains controversial.

In humans, fMRI studies showed increased activity in the HP while performing a virtual orientation task. Maguire et al. (2000) found that the long duration navigation exercise correlated positively with the volume of right posterior HP and negatively with the anterior HP. But these studies remained open the role of the innate or exercise factors in relationship between spatial performances and HP volume.

Studies with animals have revealed that sex, anxiety and lesion sites in several parts of the hippocampus and lateral caudate-putamen have an influence on the exploratory strategies in MWM (McDonald and White 1994). Thigmotaxis behaviour of rats in a MWM was characteristic during the first phase of place learning with dorso-medial, but not with dorsolateral caudate-putamen lesions. However, this type of lesion had no influence on the hidden platform acquisition in the subsequent test trials. On the other hand, a dry-land maze design study showed that both the lesion groups spent less time in the vicinity of the arena wall than the control rats. This latter evidenced by Devan et al. (1999) points to a contradictory phenomenon between learning and emotional processing, the communication of the hippocampus and the cortex via the caudate putamen.

We determined two objectives for the present study: (a) measurement of thigmotaxis in successive trials of various spatial navigational tasks, (b) correlations between the use of thigmotaxis strategy, spatial learning expertise and the structural volumetry of the total brain adjusted amygdale and the hippocampi.

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## Methods

### Participants

The sexual dimorphism in the spatial learning and memory performances, navigation strategy requires to investigate a homogeneous sample involving young female subjects only to study the neuro-cognitive basis of thigmotaxis strategy. 39 right-handed female undergraduate students from various faculties of the University of Pécs participated in our study. The mean age was 21.4 years (SD 1.6) with a range of 18 to 27 years. All participants were paid volunteers. The participants were given informed consent in advance about the aims and procedures of the experiment. None of them had any previous psychiatric illnesses, or any physical disabilities that would have interfered with the completion of the tasks.

### Apparatus

A computer-generated virtual arena maze (CGArena; Jacobs et al. 1997) and a real arena maze (RAM; Kallai et al. 2005) tasks were utilized to assess subjects' expertise and thigmotaxis activity.

### CGArena task

For measuring spatial performances and registering motion patterns in virtual environment, a freeware, desktop-based program was applied (<http://w3.arizona.edu/~arg>). For the CGArena, participants were tested on a standard PC displaying a coloured view of a circular arena that was located within a square room. Each wall in the room had a distinctive pattern of windows or arches, thereby providing a means by which participants could orient themselves within the virtual space. The task was presented in a first-person perspective, so the participants were looking at the scene as if standing on the floor of the arena.

### RAM task

The apparatus for measuring spatial navigation performance in a real world environment was built in a large experimental room. The basic configuration of the RAM was implemented from the circular water maze training protocol described by Morris (1982). The main features of this apparatus were the circular timber arena wall (6.5 m in diameter, 2 m in height), eight uniquely shaped geometric objects on shafts in fixed positions within this circular space, and a pressure-sensitive, circular platform on the floor, which emitted a pitched tone when the participant stepped on it (<http://www.aok.pte.hu/magtud/spacelab>).

### Magnetic Resonance Imaging (MRI) volumetry

Magnetic resonance imaging-based volumetry was performed in all cases using a method described by Watson et al. (1997). All scans were performed on a 1.0 T Siemens Magnetom Impact unit (Siemens Medical, Erlangen, Germany). The three-dimensional volumetric imaging was obtained with a Fast Imaging Steady State Free Precession (3D FISP) sequencing. Six regions of interest (ROI) were measured: hippocampus, amygdala and a 3-mm thickness of hemisphere on both sides. Absolute volumes of the right, left, and the total hippocampus and that of the amygdala were defined independently by two observers.

### Procedure

#### *CGA task*

Inside the test room, there were distal objects on the walls and a blue rectangular platform on the floor, which was visible in the first two trials (Trial 1 and Trial 2) and invisible from Trial 3 to Trial 10. The task of the participants was to find and navigate onto this target platform under the shortest time possible, and to remember its position. The position of the distal objects and the platform was constant during all the trials. If the participants failed to find the platform within the 3 min, the programme teleported them to the next trial.

#### *RAM task*

The participants were instructed to learn the spatial order of a visually deprived environment and to find a way to a target in an arena form maze. The RAM had two doors (an entrance and an exit) on the west and south walls. Before entering the RAM, the participants were fitted with non-transparent goggles to exclude any visually driven searching. They had to rely on their haptic senses to locate the landmarks and the target escape platform throughout the whole RAM task. In this way, the experimental design impels participants to record the spatial relations among navigation signals and to use allocentric reference-based navigation. After finding the target disc successfully, the participants were allowed a fixed time to explore the surrounding objects. There were seven trials, and each trial lasted 5 min with a 2-min interval between them.

### Data analyses

Platform-finding time and path maps were obtained for each task and each trial. Search strategies are composed of repeated trajectory patterns that form distinct parts of a participant's path map. The present investigation focused

on the investigation of neuro-cognitive basis of human thigmotaxis only.

## Results

The regression analysis revealed that the overall thigmotaxis activity of CGArena was predictive to both CGA ( $R^2 = 0.401$ ,  $\beta = 0.634$ ,  $p < 0.001$ ) and RAM ( $R^2 = 0.255$ ,  $\beta = 0.505$ ,  $p < 0.001$ ) platform-finding success. Participants with more thigmotaxis performed poorly in the place-learning tests in both environments.

As in a previous study, the search strategies are dynamically changing in time as the participants learn to locate the invisible platform. Considering these results, the prevalence of thigmotaxis was analysed from trial to trial. The analysis revealed that thigmotaxis in the CGA Trial 2 and Trial 4 was predictive of the CGA spatial learning performances ( $R^2 = 0.414$ ,  $\beta = 0.408$ ,  $p < 0.05$ ). The results indicate that after Trial 4 there is an intensive thigmotactic strategy shift in the process of the spatial learning.

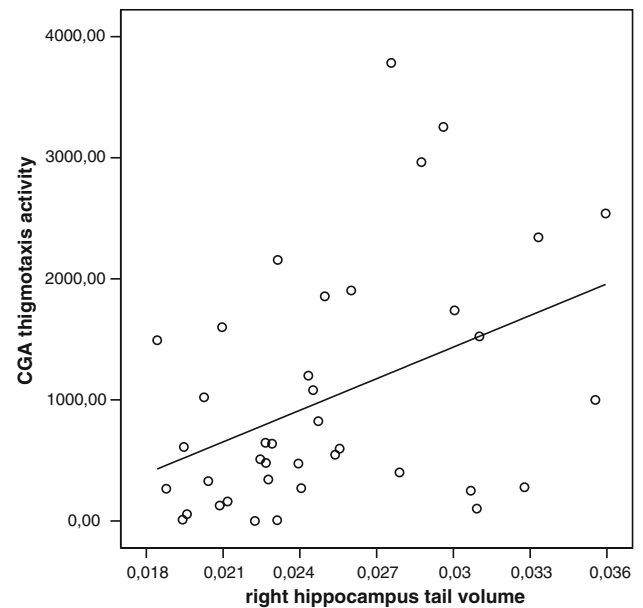
A similarly crucial point was identified in the case of the RAM task. Depending on the RAM platform-finding time, Trial 3 and Trial 4 were found to be predictive for the final performance ( $R^2 = 0.350$ ,  $\beta = 0.373$ ,  $p < 0.05$ ). It showed that the thigmotaxis activity in the middle part of place learning in both arena tasks predicts platform-finding success.

Stepwise regression analyses with the assessed anatomical structures revealed that the volume of right posterior hippocampus and the left amygdala together predicted spatial learning performances in the CGA task ( $R^2 = 0.363$ ; right posterior hippocampus,  $\beta = 0.311$ ,  $p < 0.05$ ; left amygdala,  $\beta = 0.414$ ,  $p < 0.05$ ). The right posterior hippocampus volume also predicted the platform-finding efficiency in the RAM task ( $R^2 = 0.137$ ,  $\beta = 0.371$ ,  $p < 0.05$ ).

Our final regression model aimed to establish the relationship between thigmotaxis activity and the investigated brain area volumes. Thigmotaxis in the CGA task could be predicted on the basis of the posterior hippocampal volume ( $R^2 = 0.202$ ,  $\beta = 0.449$ ,  $p < 0.05$ ). However, thigmotaxis in the RAM could not be predicted by the hippocampus volume ( $R^2 = 0.200$ , n.s.) (Fig. 1).

## Discussion

Thigmotaxis, as an element of the social behaviour, is aimed at solving uncertain situations; a strategy to avoid unprotected areas. It is definitely more pronounced in animals with high level of anxiety. Laboratory experiments



**Fig. 1** Relationship between thigmotaxis activity and right posterior hippocampal volumes

with anti-anxiolytic agents focusing on thigmotaxis in the process of novel space exploration made it clear that such wall following behaviour is part of the phylogenetically prepared set of fear reactions and is a major index of emotionality and anxiety. Our result revealed that this anxiety-related exploratory strategy can be identified in humans as well. A detailed statistical analysis demonstrated that the latency of the escape platform finding depends on the rate of the thigmotaxis in the middle part of the trials but does not depend on the thigmotaxis activity in the first trial. Based on previous findings in this field (Fanselow 2000; Kallai et al. 2005), the first trial is considered as a habituation phase of a novel situation. During the habituation process, while calibrating the undefined space, participant's attach to the outer borders of the enclosed place has been observed. The middle part of the trial serves as the starting point to detach from the egocentric-based borders and to orient towards the central zone of the arena. These middle parts of the trials play a vast role in the temporal dynamics of place learning as is indicated by the changes in the rate of thigmotaxis. The results in both virtual and real arena task demonstrated that high thigmotaxis in the middle part of the hidden platform place-learning trials predicts poor efficiency in way-finding learning.

The spatial distribution of movement in a circular arena aimed at finding a hidden escape platform encompasses some conflicting elements. High positive thigmotaxis does not help on the quick acquisition of the spatial location of the platform (Choleris et al. 2001). Due to egocentric-related border dependence, participants with high thigmotaxis stay on the periphery of the circular arena and are

unable to find the proper navigation cues to install the space. We think that this unresolved conflict makes it impossible to find available information for the construction of a spatial map. The present findings support the earlier hypothesis that (Kallai et al. 2007) thigmotaxis originated from an uncertain territorial fear is considered to play an essential role in preparing the first phase of spatial learning and in defining the outer borders of a given place. It serves as a starting point for constructing the elements of the egocentric reference frame, and also as a base for building up a cognitive map. Spatial learning is only impaired in the case of prolonged thigmotaxis, which points far beyond the first phase of the learning process and indicates reduced behavioural flexibility or total inability to switch to an appropriate search strategy. Our results support the ideas coming from animal researches, explicated by Devan et al. (1999) who claim that rigidity or inability to change from one position to another indicates a limited chance to strategy selection.

## References

- Choleris E, Thomas AW, Kavaliers M, Prato FS (2001) A detailed ethological analysis of the mouse open field test. *Neurosci Behav Rev* 57:253–260
- Devan BD, McDonald RJ, White NM (1999) Effects of medial and lateral caudate-putamen lesions on place- and cue-guided behaviours in the water maze: relation to thigmotaxis. *Behav Brain Res* 100:5–14
- Fanselow MS (2000) Contextual fear, gestalt memories, and the hippocampus. *Behav Brain Res* 110:73–81
- Jacobs WJ, Laurance HE, Thomas KGF (1997) Place learning in virtual space. I. Acquisition, overshadowing, and transfer. *Learn Motiv* 28:521–541
- Kallai J, Makany T, Karadi K, Jacobs WJ (2005) Spatial orientation strategies in morris-type virtual water task for humans. *Behav Brain Res* 159:187–196
- Kallai J, Karádi K, Bereczkei T, Jacobs WJ, Nadel L (2007) Panic disorder with agoraphobic patients' spatial exploration in an extended labyrinth. *Psychiatry Res* 149:223–230
- Maguire EA, Gadian DG, Johstrude IS, Good CD, Ashburner J, Frackowiak SJ, Frith CD (2000) Navigation related structural changes in the hippocampi of taxi drivers. *PNAS* 97:4398–4403
- McDonald RJ, White NM (1994) Parallel information processing in the water maze: evidence for independent memory systems involving dorsal striatum and hippocampus. *Behav Neural Biol* 61:260–270
- Morris RGM (1981) Spatial localization does not require the presence of local cues. *Learn Motiv* 12:239–260
- Watson C, Jack CR, Cendes F (1997) Volumetric magnetic resonance imaging: clinical applications and contributions to the understanding of temporal lobe epilepsy. *Arch Neurol* 54:1521–1531