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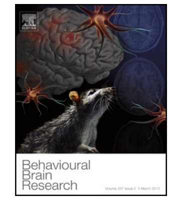

Research report

Neuroticism and self-evaluation measures are related to the ability to form cognitive maps critical for spatial orientation

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ABSTRACT

Trait neuroticism is suggested to be related to measures of volume and function of the hippocampus, a brain structure located in the medial temporal lobe that is critical for human navigation and orientation. In this study, we assessed whether measures of trait neuroticism and self-concept are correlated with the human ability to orient by means of cognitive maps (i.e. mental representations of an environment that include landmarks and their spatial relationships). After controlling for gender differences, which are well-known in spatial orientation abilities, we found that measures of neuroticism (i.e. negative affect, emotional stability) and self-concept (i.e. self-esteem) were correlated with individual differences in the rate at which cognitive maps were formed; the same measures were generally unrelated to the ability to make use of cognitive maps, as well as the ability to orient using visual path integration. The relationships (and lack thereof) between personality traits and the spatial orientation skills, as reported in the present study, are consistent with specific neural correlates underlying these factors, and may have important implications for treatment of disorders related to them.

1. Introduction

The capacity to successfully navigate throughout familiar and unfamiliar environments is necessary in daily life activities; such as travelling to and from work; or finding your vehicle in a parking lot [1]. While these tasks can be accomplished using a variety of navigational strategies; the most efficient and flexible approach relies on the ability to form a cognitive map [2,3]. A cognitive map is a mental representation of environmental landmarks and their spatial relationships; which once formed allows individuals to reach a target place from all possible locations in an environment [4]. Among a variety of strategies available for navigation; the ability to form a cognitive map is most strongly associated with a self-reported measure of environmental spatial ability [5].

The ability to orient in spatial surroundings is supported by a large number of cognitive processes, as spatial information first needs to be generated from different sensory modalities [6], contained and maintained in short and long term memory [7], and finally recalled and manipulated to direct behaviour [8]. Due to the diverse cognitive processes involved in navigation and orientation, it is not surprising that a large neural network is recruited during these behaviours, including frontal, parietal, and temporal regions of the brain [3,9]. Among this network, the hippocampus has been found to play a predominant role in spatial memory tasks [10]. The importance of the hippocampus in spatial orientation was first observed in rodents [4], and later in humans both structurally [11,12] and functionally [13,14], and hippocampal damage impairs the ability to navigate throughout an environment relying on a cognitive map [15,16]. In sum, in the context of spatial orientation and navigation, there is strong evidence in both animal and human research that the hippocampus plays a critical role in the formation and use of a cognitive map.

Interestingly, many anxiety-related disorders are associated with differences in hippocampal structure and function. For example, individuals with Post-Traumatic Stress Disorder (PTSD) and those with Major Depressive Disorder (MDD) generally have lower hippocampal volume [17,18] and altered hippocampal function

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[19,20], as compared to healthy controls. Neuroticism, a personality trait associated with frequently experiencing negative emotions, such as anxiety, anger, and self-consciousness [21], is a risk factor for the aforementioned disorders [22,23]. In non-clinical populations, increased measures of anxiety and neuroticism are correlated with decreased hippocampal volume [24,25], and altered hippocampal activity [26,27]. Neuroticism, or emotional instability, is one of the factors of the Five-Factor personality model [28], as well as one of the four dimensions of human core self-evaluations, the subjective assessment of one's own abilities and control over themselves, others, and the world [29]. Generally, individuals scoring high on levels of neuroticism have lower self-esteem, a more external locus of control, and lower self-efficacy [30]. Additionally, measures of self-esteem are positively correlated with measures of hippocampal volume [31,32]. Although not consistently discussed in studies assessing neuroticism and self-concept, the hippocampus appears to be a part of the neural substrate of both of these traits.

There is evidence of a neurological link, relying on the hippocampus, between measures of spatial memory and anxiety-related behaviours [33]. We therefore hypothesized that the ability to form cognitive maps for orientation and measures of neuroticism and self-concept are related. We tested this hypothesis in the current study by asking a group of healthy volunteers to perform spatial orientation tasks and complete a series of questionnaires that assess personality traits related to self-concept and the neuroticism factor of the Five-Factor Model. Specifically, given the evidence of increased hippocampal volume associated with strong navigational skills [11], positive self-concept [32], and low neuroticism [34] levels, we hypothesized that performance on hippocampal-related spatial tasks are positively correlated with measures of self-concept and negatively correlated with measures of neuroticism.

2. Materials and methods

2.1. Participants

We recruited 179 healthy volunteers (135 females, age range 18–35 years, $M = 20.26$, $SD = 2.45$) from the University of Calgary undergraduate population. When asked, participants reported no history of neurological disorders, brain injuries or psychiatric illnesses, memory defects, other cognitive difficulties, nor use of any medications. Participants provided informed consent as required by the institutional ethics board (CFREB #6286).

2.2. Experimental procedure and tasks

We first asked participants to complete a demographic questionnaire, followed by two spatial orientation tests and a battery of measures assessing neuroticism-related personality traits, in an order chosen by the participant from the list of available tasks generated by the testing software.

2.2.1. Spatial orientation tasks

We asked the participants to solve our cognitive map test [5], which consisted of two separate tasks, namely the cognitive-map-formation and cognitive-map-use tasks. This test was used to characterize an individual's capacity to orient and navigate in large-scale environments. In the formation phase of this test, participants are shown a series of one-minute clips depicting ground-level movement in a persistent virtual environment. The virtual environment consisted of a 5×5 rectangular grid of buildings, four of which were distinct landmarks, and the others identical, non-descript buildings. The virtual environment did not include any global environmental cues (e.g. the sun, mountains) since the task aims to assess the ability to create a mental representation of spatial relationships between landmarks encountered while navigating. After each video clip, the participants were asked to indicate the positions of the four landmarks on an aerial view of the environment. This response format partially addresses individual difference skills in drawing sketch maps, although some transformational skills may still be required to report landmark positions on the map. Trials continued until the correct spatial layout of landmarks was identified, or twenty trials elapsed (in which case the participants were recorded as solving in 21 trials). We recorded the number of trials required to solve the task, and inverted them so that higher scores represented a stronger ability to form a cognitive map. This test has been shown to be correlated with self-reported sense of direction [5], and although the task utilized passive exploration, it engages similar neural structures as other active exploration tasks [35]. This supports the validity of this task in measuring the ability to form cognitive maps, although passive navigation may result in slower learning as compared to active navigation [36]. After the formation phase, participants were shown the correct aerial view of the environment for 20 s, and then began the cognitive-map-use task. This task consisted of twelve trials (two practice, ten scored) in which participants were shown a target location and a starting viewpoint in the environment as encountered in the formation phase. Participants were asked to indicate, from the viewpoint shown, if a left or right turn would initiate the shortest path to the target location. Each starting viewpoint was presented at ground level, and faced one of the distinct landmarks to assist participants in orienting themselves within the environment. Higher scores on the cognitive-map-use task represent a stronger ability to make use of a cognitive map. The cognitive-map-use task measures the initial decision that individuals make based on their knowledge of the environment, without measuring the ability to navigate to a given location. Fig. 1 contains sample images representing the tasks and environment. This test measures the ability to form and make use of cognitive maps, although it remains unclear what kind of mental representation individuals form and subsequently use in order to retrieve spatial information for the purpose of orientation and navigation [13].

In addition to the cognitive map test, we asked participants to perform our path integration test [5]. In this test, participants were shown twelve video clips (two practice, ten scored) of first-person movement throughout a featureless environment with a textured floor. The path taken in the video clips was always in the shape of a right-angled triangle, with the final portion of the path along the hypotenuse. In two-thirds of the video clips, the position of the camera stopped either before or after the starting point, and in the other third, the position of the camera stopped on the same place it started. Trials were randomized, and participants were asked to indicate if the camera stopped on the same place that it started for each clip. Higher scores on the path integration test indicate a stronger ability to use visual self-motion cues to keep track of changes in position and orientation [37]. This task was included as a non-hippocampal spatial control task [38]. A sample image of the path integration task is shown in Fig. 1D. The cognitive map test and the path integration test were developed in our laboratory and previously used for behavioural [5] as well as neuroimaging [35,38] studies.

Finally, we asked participants to complete the Santa Barbara Sense of Direction Scale (SBSOD) which is designed to measure a participant's self-reported orientation skills as experienced in their daily life [39]. The SBSOD consists of 15 items (e.g. "I am very good at judging distances") on a 7-point Likert scale ranging from *strongly agree* (1) to *strongly disagree* (7). Scores on positively worded items were transformed such that higher scores are indicative of a greater perceived sense of direction.