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Decreased theta power at encoding and cognitive mapping deficits in elderly individuals during a spatial memory task

Ségolène Lithfous [a,*], Delphine Tromp [a], André Dufour [a,b], Thierry Pebayle [b], Romain Goutagny [a], Olivier Després [a]

[a] Faculty of Psychology, Laboratoire de Neurosciences Cognitives et Adaptatives (LNCA), UMR 7364—UNISTRA/CNRS, Strasbourg, France
[b] Centre d'Investigations Neurocognitives et Neurophysiologiques (CI2N), UMS 3489—UNISTRA/CNRS, Strasbourg, France

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ABSTRACT

The purpose of this study was to investigate the role of theta activity in cognitive mapping, and to determine whether age-associated decreased theta power may account for navigational difficulties in elderly individuals. Cerebral activity was recorded using electroencephalograph in young and older individuals performing a spatial memory task that required the creation of cognitive maps. Power spectra were computed in the frontal and parietal regions and correlated with recognition performance. We found that accuracy of cognitive mapping was positively correlated with left frontal theta activity during encoding in young adults but not in older individuals. Compared with young adults, older participants were impaired in the creation of cognitive maps and showed reduced theta and alpha activity at encoding. These results suggest that encoding processes are impaired in older individual, which may explain age-related cognitive mapping deficits.

1. Introduction

Many studies have reported an age-related decline in spatial navigation (Klencklen et al., 2012; Lithfous et al., 2013; Moffat, 2009). These deficits concern especially the creation of cognitive maps of novel environments and seem to affect route knowledge (Head and Isom, 2010; Mahmood et al., 2009) as well as survey knowledge (Head and Isom, 2010; Iaria et al., 2009; Mahmood et al., 2009; Moffat and Resnick, 2002; Moffat et al., 2001). By contrast, long-term spatial representations stored in memory seemed to be relatively preserved because older adults were still able to find their way in familiar environments, even after not visiting them for many years (Rosenbaum et al., 2012).

Functional neuroimaging studies in healthy young subjects have contributed evidence supporting the notion that a distributed cerebral network is involved in spatial navigation. This network has been found to include the medial temporal lobes, particularly the hippocampus and the parahippocampal gyrus; the parietal cortex; the retrosplenial cortex; the frontal lobes, and the caudate nuclei (Gron et al., 2000; Hartley et al., 2003; Maguire et al., 1998; Wolbers and Buchel, 2005; Wolbers et al., 2004; see Lithfous et al., 2013 for review). Age-related deficits in spatial navigation have been associated with modifications of these cerebral activations. In particular, activations of the hippocampus and parahippocampal gyrus, as well as the retrosplenial cortex and regions of the parietal cortex were found to be reduced in older compared with younger adults during navigation tasks in virtual unfamiliar environments (Antonova et al., 2009; Konishi et al., 2013; Moffat et al., 2006). Hypoactivations in elderly individuals of some of the same neural systems that support navigation in the young suggest that neural changes in these cortical regions may underlie age-related behavioral impairments (Moffat et al., 2006). Thus, neuroimaging studies have highlighted modifications of the neural networks sustaining spatial navigation that may explain age-related navigational deficits. However, little is known about the neural mechanisms among these structures during spatial navigation, especially in elderly individuals. This study was therefore designed to investigate cerebral oscillations during the creation of a cognitive map in the environment and their possible modifications during aging.

Cerebral oscillations can be viewed as rhythmic changes in cortical excitability associated with stimulus processing (Fries, 2005) and may influence long-range neuronal communications among brain areas (Fries, 2005; van Elswijk et al., 2010; Womelsdorf et al., 2007). In vitro studies have contributed to evidence showing band-specific neural activity, including delta (1–4 Hz), theta (4–8 Hz), alpha, (8–12 Hz), beta (12–30 Hz), and gamma (>30 Hz) bands (Bishop, 1933; Buzsaki and Chrobak, 1995;

* Corresponding author at: Laboratoire de Neurosciences Cognitives et Adaptatives, UMR 7364 UNISTRA/CNRS, 21 rue Becquerel, 67087 Strasbourg Cedex, France. Tel.: +33(0)3 88 10 67 43; fax: +33(0)3 88 10 62 45.
E-mail address: lithfous@unistra.fr (S. Lithfous).

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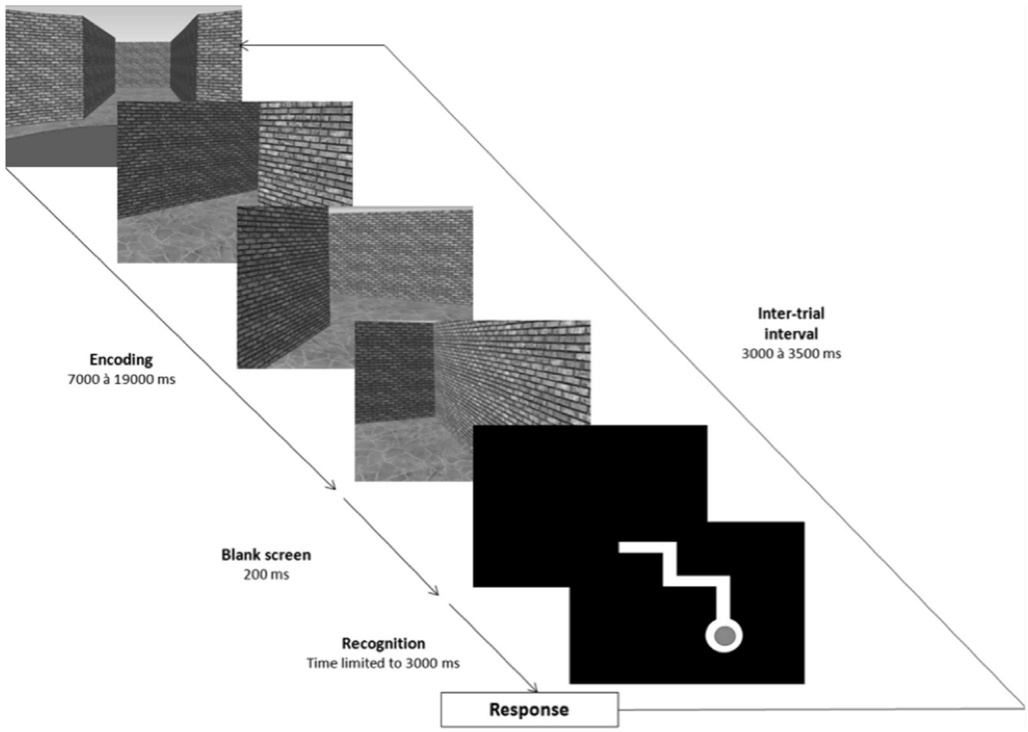

Fig. 1. Experimental procedure. Images are captured from a video and show the maze where the path was passively traveled. The encoding phase corresponded to the viewing of the path in the maze, with a ground level perspective, and ranged from 7000 ms to 19,000 ms as a function of the length of the path and the number of turns (3–5). This phase was followed by a blank screen for 200 ms. Then, a map was presented, which congruent or not with the path encoding with a ground level perspective. Subjects had 3000 ms to indicate whether the map corresponded to the path encoded or not, by pressing respectively the right or left arrow key. The next trial began after the subject's response or after the imparted delay.

Freeman, 1975; Mitzdorf, 1985). More particularly, low frequency oscillations are thought to modulate activity over large spatial regions and long temporal windows, whereas high frequency oscillations may modulate activity over smaller regions and shorter temporal windows (von Stein and Sarnthein, 2000).

Low frequency cerebral oscillations have also been associated with memory processes (Ekstrom and Watrous, 2014; Klimesch, 1996; Klimesch et al., 2008).

In the context of spatial memory, theta activity has been associated to encoding of spatial locations during the creation of a cognitive map (Ekstrom et al., 2005; Montgomery et al., 2009; O'Keefe and Recce, 1993; Watrous et al., 2011). Intracranial recordings in humans have shown that cell firing in the hippocampus and the neocortex during free exploration of a virtual environment is organized by theta frequency (Ekstrom et al., 2005). Moreover, theta activity during free exploration of a virtual environment has been shown to predict subsequent object location recall accuracy (Snider et al., 2013).

The purpose of this study was 2-fold. First, we investigated the role of theta activity during the creation of cognitive maps. We hypothesized that increased theta activity during encoding of a path will be associated with successful recognition performances of this path presented from a survey perspective. Second, we investigated whether theta activity is altered during aging and whether this decrease is associated with deficits in spatial navigation. To test these hypotheses, we recorded neural activity of young and elderly participants using electroencephalograph while they performed a spatial memory task that required the creation of a cognitive map. Subjects encoded a path in a 3-dimensional environment (i.e., a virtual maze) from an observer perspective. They were then shown a 2-dimensional map of the path (i.e., survey perspective) and had to indicate whether or not it corresponded to the path encoded. Spectral power was computed in frontal and parietal areas during encoding, followed by correlation analyses between spectral power at encoding and recognition performance, to determine whether neural activity at encoding could predict the accuracy of the cognitive map.

2. Methods

2.1. Participants

The participants included 22 young subjects (11 men, 11 women; mean age, 24.42 years; standard deviation [SD], 2.54 years; age range: 21–29 years) and 20 older subjects (11 men, 9 women; mean age, 65.82 years; SD, 4.75 years; age range: 60–73 years). All were right handed, had normal (i.e., non-corrected visual acuity better than 20/25 binocularly) or corrected to normal vision and were free of neurological and psychological disorders, as determined by detailed self-reported medical histories. The intake of drugs, medication known to alter cognition (e.g., anti-epileptics, neuroleptics) or a daily consumption above 9 cigarettes or 20g of alcohol constituted exclusions criteria. Older participants were screened for dementia using a complete neuropsychological examination (see Section 2.2). Most of the younger participants were recruited from the local university, and older subjects were recruited via advertisements. Mean education level were 14.7 $\pm$ 1.9 years for the young and 13.73 $\pm$ 2.8 years for the older group. All participants were paid and provided written informed consent before participation, in accordance with the guidelines of our local ethics committee, which approved the study.