Keywords: mild cognitive impairment, Alzheimer’s disease, cognitive training, spatial orientation

Background
Previous research has found an age-related decline in the cognitive skills that are critical for spatial orientation and navigation. For example, attention, perception, memory, mental imagery, and decision-making skills have all been shown to decline with age. (Kirasic, 2000; Iachini, Ruggiero, Ruotolo, & Pizza, 2008). Decreases in these specific skills have a great impact on the most complex spatial orientation skill—the ability to form a mental representation of an environment—which shows the largest decline in later adulthood (Iaria, Palermo, Committeri, & Barton, 2009). The loss of spatial skills increases with age (Liu, Levy, Barton, & Iaria, 2011) and can have debilitating effects on the independence of senior citizens (Burns, 1999).

These spatial impairments are especially pronounced in people diagnosed with Mild Cognitive Impairment (Mapstone, Steffenella, & Duffy, 2003) and Alzheimer’s Disease (Braak, & Braak, 1991). Mild Cognitive Impairment has been suggested to be a precursor for Alzheimer’s Disease (Morris et al., 2001). Recently, studies have documented the spatial deficits caused by Mild Cognitive Impairment and Alzheimer’s Disease. These studies have concluded that training the cognitive skills involved in spatial orientation may have therapeutic value, especially as a preventative measure during the early stages of disease progression (Iachini et al., 2009).

In the context of aging and dementia, it is essential to understand how cognitive training can be used to prevent and reverse the decline of spatial skills to help promote well-being and independence. It is also important to determine how cognitive training can slow disease progression for people with Mild Cognitive Impairment and Alzheimer’s Disease.

Objectives
1. Investigate the impact of cognitive training on a variety of spatial navigation skills that are known to deteriorate with age, and a result of Mild Cognitive Impairment and Alzheimer's Disease.
2. Investigate the neural mechanisms associated with spatial orientation.

Method
Due to a low referral rate of patients with Mild Cognitive Impairment, we were unable to complete their first objective. Therefore, we focused on their second objective of understanding the neural mechanisms underlying spatial orientation.

Neuroimaging was conducted at Foothills hospital in Calgary, Alberta. Fourteen healthy young individuals, 9 individuals with a cognitive deficit called Developmental Topographical Disorientation, and 9 healthy control participants who were matched to the previous group for age and gender were recruited. Each group of participants was scanned using magnetic resonance imaging. High resolution anatomical images of participants’ brains both during a series of orientation tasks, and while in a resting state were acquired. Two studies were conducted on this data.
The first study looked at the neural mechanisms underlying the capacity to make accurate orientation judgments in familiar environments using the sample of 14 healthy young individuals. The regions of neural activity associated with orientation decisions were identified using a partial least squares algorithm.

The second study looked at the neural mechanisms associated with Developmental Topographical Disorientation. This cognitive deficit is associated with a lifelong inability to encode the spatial layouts of environments. This results in decreased abilities to spatially navigate and has a wide-reaching impact on personal autonomy. Understanding how Developmental Topographical Disorientation operates at a neural level can help develop theories about how spatial memory works in the brain. For this study, we looked at patterns of brain region communication with the hippocampus.

Results
The first study found that spatial orientation abilities strongly depend on the capacity of spatial memory networks to integrate information. This suggests that either brain training or disease-related changes in orientation ability may be related to changes in the efficiency of spatial memory networks.

The second study found that Developmental Topographical Disorientation appears to be related to decreased connectivity between the hippocampus and the prefrontal cortex. This suggests that deficits in spatial orientation and navigation may be caused by variability in how brain regions interact, and not just tied to one region alone.

Conclusions
Although we could not complete the brain training portion of the study due to a low referral rate, we were able to provide important advances in understanding how spatial orientation operates at a neural level. These findings have important implications for measuring the influence of brain training paradigms in the healthy population, and determining rehabilitative strategies for persons showing spatial deficits.

The Developmental Topographical Disorientation study provided the first insight into how the disorder operates at a neural level and provides a potential benchmark that can be developed through future research to help clinicians correctly identify individuals with Developmental Topographical Disorientation.

The most important follow-up study from this research will be to evaluate the relationship between brain training, neural plasticity, and clinical rehabilitation. Future studies can use these results to investigate the relationship between brain training paradigms in healthy and spatially-impaired populations, as well as changes in structural and functional connectivity in spatial memory networks. This would identify how brain training changes the mechanisms of spatial orientation, and allow researchers and clinicians to determine how effective training paradigms can be.

Lessons Learned
Since our study had a low referral rate, future projects could benefit from recruiting from more sources, aside from just hospital referrals. Other possible sources include community and assisted living facilities.

The central finding of this project is that spatial memory is related to a distributed network in the brain, rather than being the activity of a single brain region. In a clinical context, this is an important insight because biological networks such as the brain are known to exhibit degeneracy, which allows a network to produce behaviour even if part of the network is negatively impacted. Traditionally, spatial memory was thought to be lost if the hippocampus (the brain region alleged to be solely responsible for encoding spatial environments) was damaged. Our findings suggest this may not necessarily be the case. We argue that spatial memory ability can be at least partially preserved and rehabilitated through strategic interventions that assist in the functional reorganization of neural networks.

The full report can be found at www.mentalhealthresearch.ca
References


About the Author: Aiden Arnold (University of Calgary) is a visiting research scholar in the Center for Neuroscience at the University of California Davis and a PhD candidate with NeuroLab at the University of Calgary. His research focuses on understanding how the brain represents environmental information through memory processes, and how we can use that information to design better rehabilitative strategies and technologies to assist people with memory deficits.