CIS2 - Paper Review
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Group 7: Cognitive Training Quiz Application
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On "Vestibular involvement in cognition: Visuospatial ability, attention, executive function, and memory"

We selected the paper, "Vestibular involvement in cognition: Visuospatial ability, attention, executive function, and memory," by Bigelow et al. We do so because it provides context and motivation for our project, "A Cognitive Training Quiz Application." This review paper touches upon the general methods and principles of how cognitive visuospatial ability has been assessed and measured in the clinical setting. The purpose of the web application we've built is to provide cognitive training exercises, and assess the visuospatial abilities of elderly patients. Building upon established methodology lends validity to our approach, and also facilitates more facile evaluation of the effectiveness of our application; indeed, as we've essentially converted verbatim a set of existing pen-and-paper exercises and assessments used in the clinical setting, there exists a readily available basis for comparison. While the studies reviewed by this paper focus on the contribution of the inner-ear vestibular system, the methods used in assessing patients' visuospatial abilities are not solely limited to this scope; indeed, these methods have been used to experimentally investigate the effect of myriad factors on cognitive ability, and can be considered a somewhat universal measure.

To paraphrase from the paper itself, visuospatial ability is the ability of the human mind to comprehend and organize space. Several skills used in everyday cognitive tasks fall under its purview, including spatial memory, navigation, and mental rotation; spatial memory is the ability to retain certain types of information about the surrounding environment, such as geometry, relative positions, distances, sizes, and orientations. Navigation is the ability to move purposefully through the environment. Mental rotation is the ability to determine whether images displayed at different orientations are identical to one another.

One method by which spatial memory is assessed is the Morris water navigation task. Inside a pool of opaque water, there is a submerged hidden platform that allows escape from the pool. The participants are repeatedly placed in this pool, and using external visual cues, must navigate to this platform without being able to see it. While ordinarily this assessment is performed on animals, usually rats, a digital version of the Morris water task has been used in order to assess spatial memory in humans. Using the virtual Morris Water Maze Task, studies have shown that patients with bilateral vestibular dysfunction performed worse than the control group, with longer path length and decreased time spent in the correct quadrant. Another method by which spatial memory is assed is the Corsi block test, where participants are shown a sequence tapped on a set of numbered blocks. Indeed, one of the exercises that our application implements is a variation of the Corsi block test. The participants are asked to repeat the sequences, which grow progressively longer until they are no longer able to reproduce the pattern. Studies performed with this test showed that patients with vestibular neuritis performed worse than the control group. These are interesting results because while it's commonly known that the inner ear contributes to the sense of balance, neither of these tests require any physical movement from the participants; the virtual water maze task is completed on the computer, and the block test can be done while stationary. Indeed, a deficit in the sensory apparatus of the inner ear seems to have real and detrimental effects on cognitive ability.

Spatial navigation is typically assessed by having subjects move along memorized paths or towards memorized targets. Somewhat more intuitively than the previous result, studies find that patients with vestibular dysfunction have impaired navigational ability, particularly when their eyes are closed, and they have to rely solely on their awareness of their position for navigation. While loss of vestibular function is compensated by vision and somatosensory cues, this cognitive deficit persists even after internal balance has been restored and symptoms of vertigo have subsided. Furthermore, patients who were suffering from a temporary deficit in their vestibular function, for example, resultant from a lesion that later healed, showed later improvement in their navigational ability. In those patients whose defects were permanent, improvement in navigational ability could also be achieved after rehabilitative exercises. While it's impossible to present a perfect digital analog of the task of walking, we attempt to provide a means of measuring spatial navigational ability via a series of map navigation tasks.

Mental rotation is assessed by showing subjects two similar objects in different orientations. These subjects are asked to determine whether or not the two objects which they have been shown are identical. As this is, like the block test and virtual water maze tasks, a purely cognitive task, it is somewhat non-intuitive that studies find that patients with vestibular deficits also perform worse, with slower task completion and higher error rate than control, on tasks involving mental rotation. Essentially, the findings of the studies suggest that vestibular input is important in how the brain forms a mental representation of three-dimensional space. Alteration or removal of this input leads to cognitive deficits related to visuospatial tasks.

Because there is not any obvious explanation for these findings, other studies were done in order to determine the mechanism by which vestibular impairment causes decreased visuospatial cognitive function. One model, Kahneman's Capacity Model of Attention, hypothesizes that an individual has a limited amount of attention and cognitive resources available to allocate to mental tasks. While ordinarily balance is a reflexive task, individuals who have impaired vestibular function, even after compensation, must expend attention and cognitive resources in order to maintain balance. With fewer resources, performance on other cognitive tasks is diminished. Studies in which patients were asked to perform two tasks simultaneously, such as maintaining a certain posture, or keeping balance while on a moving platform, while counting backwards or pressing a button in response to auditory cues, showed that patients with vestibular deficits showed greater response latency and decreases in accuracy compared to healthy individuals. These findings seem to support the hypothesis that maintaining balance requires a greater degree of attention in vestibular-impaired individuals, thus contributing to cognitive impairment. Indeed, cognitive function in general seems to be decreased due to this additional strain, not merely visuospatial tasks.

For the most part, the conclusions reached by this review are sound, as it considers a wide range of studies regarding the contribution of the inner ear vestibular system on cognitive visuospatial ability. In general, though, the sample sizes for the studies were fairly small; most of the studies had around 15 patients, and an equal number of controls. The 2002 dual-task study by Yardley et al, which yields the most compelling evidence for Kahneman's Capacity Model, however, had 24 controls and 48 patients with vestibular disorders. Yet while this finding supports that hypothesis, studies have shown that in regular testing situations, with just a single task at hand, patients with vestibular disorders also perform more poorly than the healthy control group. Therefore, the nature of the visuospatial cognitive deficit linked with vestibular disorders is not made entirely clear.

While our project is concerned not merely with assessing patients' cognitive visuospatial abilities, but also to provide training that will help them to improve, in many ways our work follows up on the studies presented by the review. As far as assessment is concerned, we attempt to assess the same major components of visuospatial ability, using fairly analogous methods as described and have been validated by prior studies. This is likely due in large part to the fact that our application is modeled after an existing pen-and-paper assessment, which itself is backed by test studies and clinical validation. However, there is no perfect translation between the pen-and-paper medium, assisted by a therapist or physician, and a web application intended for use by the patient alone. Indeed, as far as assessing navigational ability goes, there is no real way to remotely assess a patient's walking ability via web-app. Therefore, we rely upon the navigation-by-map methodology of the pen-and-paper exercise. In some cases, we must compensate for the lack of assistance with additional guidance; in other cases, we attempt to improve upon the existing procedure by taking advantage of the web application's capacity for additional interactivity, without compromising the core principle behind the assessment.