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Approaching Spatial Ability in 4-Dimensional Space through an Autostereoscopic Visuospatial Perception System

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Introduction

Many real-life tasks from problem-solving to orientation require mental representations, and the term spatial ability is used to describe one's skill set in such tasks. Previous work has examined humans spatial ability in 3-dimensional (3D) space and suggests that spatial ability for higher dimensional spaces can exist as well.

4-dimensional space (4D) refers to a space that is composed of 4 spatial dimensions that are orthogonal to another. Given recent advances in rendering and displaying technology, a novel visualisation system capable of displaying 4D drawings on an autostereoscopic display was built. Using this system, the ability to form 4D mental representations under varying conditions of visuospatial perception cues was examined.

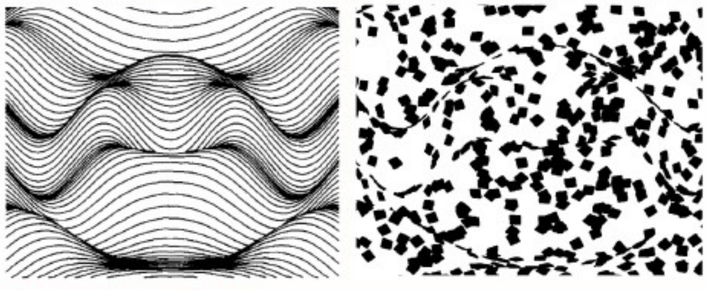
Visuospatial Perception Cues

To perceive space, humans make use of perception cues. In this paper, three kinds of perception cues have been tested for their impact on the building of 4D spatial ability.

a) **Binocular cues**: Depth perception that relies on having two eyes, such as stereopsis (perceiving depth through a static parallax perception) or vergence (perceiving depth based on the difference of in the rotation of the two eyeballs).

b) **Illumination cues**: Cues such as lighting, surface shading or aerial perspective also help us in understanding the depth and composition of the perceived scene.

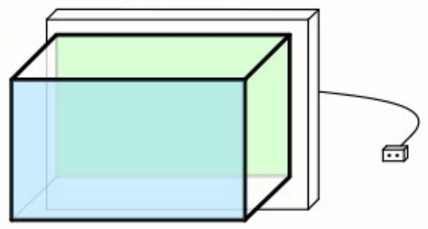
c) **Texture cues**: Surface texture allows us to reason about the structure of a surface. Given that, it also helps in spatial perception.



[Todd and Akerstrom 1987]

4D Visualisation System

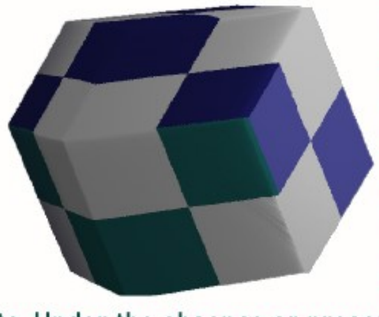
To assess one's spatial ability, a visualisation system designed around an autostereoscopic display was used. Such an autostereoscopic display displays many views at once, allowing observers to perceive a scene from multiple angles. The system is thus able to produce 3-dimensional images of 4-dimensional structures. With the use of a novel rendering algorithm, the three previously investigated visuospatial perception cues are supported by the visualisation system and can be toggled on and off individually.



Study Methods

To test the 4D spatial ability based on visuospatial cues, a case study with 5 participants has been done.

In the beginning, participants underwent a preliminary assessment of their pre-existing spatial ability in 2D and 3D, as well as their self-evaluation of their skills. Then, they were given an explanation of 4D space and the experiment stimulus, a hypercube. After that, the learning phase started, in which participants could familiarize themselves with the hypercube and play around with 4D rotations. During this phase, questions were answered.



Finally, the examination phase began. Subjects were confronted with hypercubes that had their surfaces coloured based on the cell the surface belongs to. Under the absence or presence of different visuospatial cues, it was tested whether and how fast subjects could find the cube cell opposite to a named cell. This task was designed to test the understanding of the arrangement of the presented 4D structure. Finally, an ending interview was done to gather further qualitative information. Participants spent roughly an hour with the study each.

Results

The given task was solvable with many different tactics. Among those were tactics of both a geometrical and spatial nature. In the interviews, mental images of mathematical and spatial nature were observed. Together with the results, where not only the correctness of the answers but also the time participants took, played a role, an assessment of the mental representations built by the subjects could be done.

The results show that binocular cues have a significant and intuitive impact on 4D spatial ability, as they improved the results of all participants, even when not noticed. Further, the results suggest that illumination cues and texture cues also can, to different levels, positively impact 4D spatial ability.

Impact of Visuospatial Cues on 4D Spatial Ability

Bincular Cues	Illumination Cues	Texture Cues
Intuitive Impact	Sizeable Impact	Limited Impact

Future Work

To increase the significance of the study, more perception cues such as eye accommodation or object reflections need to be tested, with more participants of a wider range of age or even groups of people.

Conclusion

The gathered evidence strongly suggests that many perception cues we know from 3D space can be transferred to 4D space. This supports previous research that suspects that spatial perception works linearly within the human brain, rather than using an spatial mental representation.

References

Todd, J.T. and Akerstrom, R.A. 1987. Perception of three-dimensional form from patterns of optical texture. Journal of Experimental Psychology: Human Perception and Performance 13, 2, 242–255.