# The Impact of Visualizations on Information Processing Efficiency: Multivariate Visualization Methods

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**Abstrakt**

In the past, we conducted a series of research studies investigating intercultural differences in perception across various task types. The results, on the one hand, generally do not support one of the dominant intercultural theories—the analytic-holistic approach—but at the same time, they confirm significant intercultural and individual differences in perception and cognition. These differences in information processing were influenced by the level of the educational system in a given country, individual differences in expertise, as well as the visualization method itself.
One of the domains where we specifically examined individual and intercultural differences in perception was cartography, particularly the communication of spatial data. Within this context, we also focused on the subdomain of multivariate symbols. This paper comprehensively presents the series of experiments conducted and integrates partial findings.

## 1 Introduction

In recent years, our interdisciplinary research group has focused, among other topics, on the study of cartographic visualizations, particularly on the issue of multivariate symbols. This topic was explored from various perspectives—we analyzed which visualization methods are more effective in terms of the accuracy and speed of information processing, what cognitive processes are involved in perceiving these visualizations, whether specific methods are more suitable for different user groups depending on their individual characteristics, and we also examined the existence of intercultural differences in processing spatial visualizations.

## 2 Multivariate Symbols and Intercultural Differences

In one of the initial experiments focusing on intercultural comparison of cognitive processes, maps with multivariate symbols were used as a specialized type of stimulus. Performance was compared between students from the Czech Republic, representing the Western cultural area, and students from Taiwan and mainland China, representing the typical Eastern cultural area (Lacko et al., 2020).
Participants were presented with maps showing territorial units containing multivariate map symbols representing four different parameters of living costs (e.g., costs of travel, dining). Their task was to delineate a larger area (including multiple units) that they considered homogeneous. All maps were pre-generated to include two typologically distinct areas, in accordance with Norenzayan et al. (2002), who proposed two types of categorization corresponding to analytic and holistic cognitive styles:
A) An area based on a one-dimensional rule, and
B) An area corresponding to overall similarity.

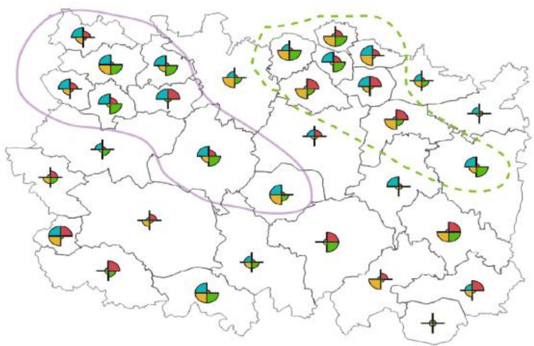

**Fig. 1**: Example of an analytic area (left—solid line) and holistic area (right—dashed line) marked on the map (source: Lacko et al., 2020)

The analysis results show that Czech participants categorized the maps more analytically, while Chinese and Taiwanese participants categorized them more holistically. This finding aligns with the theory suggesting that Western cultures tend toward analytic categorization styles, whereas Eastern cultures prefer more holistic approaches (Chiu, 1972; Norenzayan et al., 2002). Although the effect size of this statistically significant difference was relatively small, it was demonstrated that intercultural differences can be detected even with this relatively complex and specific stimulus.

## 3 Bivariate Symbols

Another research area in the context of visualization and working with spatial data focused on the use of so-called bivariate symbols, within a series of four experimental studies (Šašinka et al., 2021; Šašinka et al., 2019; Stachoň et al., 2025). In addition to investigating individual preferences related to cognitive style, the research primarily focused on the influence of visualization form on information processing performance. Specifically, two distinct visualization methods were compared: intrinsic and extrinsic.
A key methodological principle was that all experimental map variants displayed identical data content, differing only in the visualization method used. This allowed potential performance differences to be interpreted primarily as a result of differences in cognitive processing of the stimuli, rather than differences in the data itself.


**Fig. 2:** Example of bivariate legend: extrinsic (left) and intrinsic (right) (source: Šašinka et al., 2021)

The experimental design and the stimulus itself consisted of four main components: textual task description, legend, map field, and solution selection area. This setup made it possible to track not only participant performance—in terms of response speed and accuracy—but also the detailed course of cognitive processing using eye-tracking technology. This enabled us to analyze, for example, fixation durations on specific areas of interest (AOIs) and transitions between these areas, providing valuable insights into visual scanning strategies and information processing during task solving.

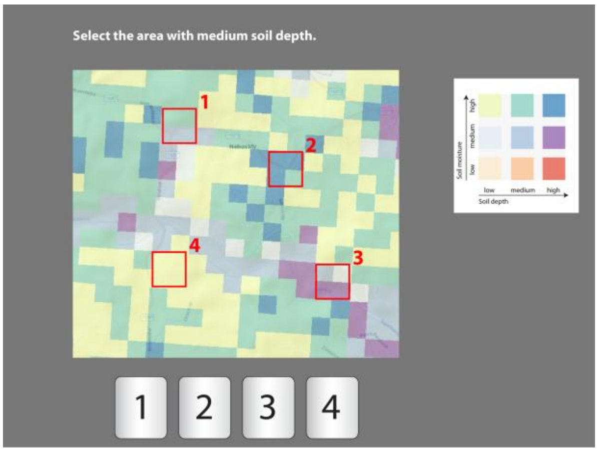


**Fig. 3:** Typical task design enabling analysis of task processing via eye-tracking (source: Šašinka et al., 2021)

The experimental results confirmed previously identified trends, such as the superiority of extrinsic visualization. However, they also showed that performance depended on the type of task and, above all, the influence of the level of expertise or map literacy on both performance and the preference for specific methods. The impact of map literacy, in particular, led us to revise our expectations regarding intercultural differences. Compared to previous studies where we examined the influence of analytic-holistic style, we focused, in the context of intercultural comparisons, on the overall educational level of the given country. The results of the intercultural comparison revealed significant differences depending on global demographic indicators.

## 4 From 2D Bivariate Symbols to 3D Visualization

The experimental design was based on previous 2D studies, ensuring comparability. However, we newly utilized eye-tracking technology integrated into VR headsets, allowing for detailed monitoring of visual attention within a fully immersive environment.

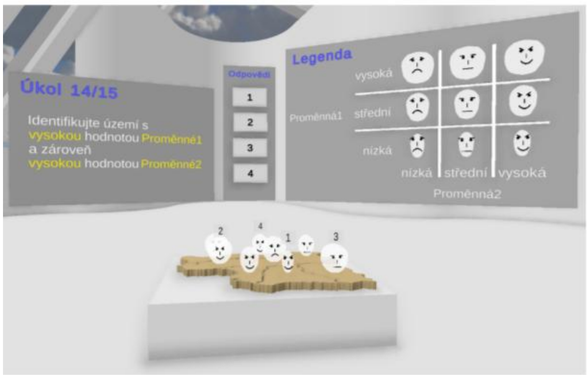


**Fig. 4:** Bivariate maps in 3D—Chernoff faces

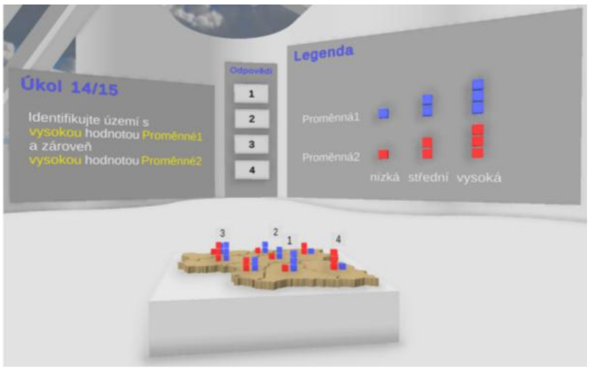


**Fig. 5:** Bivariate maps in 3D—bar charts

The results of the pilot study again demonstrated the influence of the visualization method on performance.

## 5 Conclusion

The aim of this paper is to provide a holistic perspective on research in the field of cartographic visualizations, specifically multivariate symbols. The results of the studies show that even relatively simple stimuli and task types, where an individual works with two (or four) variables, lead to differing performances depending on culture, individual differences, or visualization methods.

## Acknowledgment

This paper was supported by the Czech Science Foundation project "Identifying Barriers in the Communication Process of Spatial Socio-Demographic Information" (grant no. 23-06187S).

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