Revista Cartográfica 112 | 2026 | Artículos 169-192
ISSN (impresa) 0080-2085 | ISSN (en línea) 2663-3981
DOI: https://doi.org/10.35424/rcarto.i112.6059
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Perceptual Distortions in Map Reading

Distorsiones perceptuales con la lectura de mapas

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Received October 1, 2025; Accepted November 1, 2025

Abstract

Research on the cognitive aspects of map reading has focused on how the human mind processes information presented on maps. However, this literature has a notable gap regarding unconscious phenomena that can negatively influence the process, such as biases and optical illusions. This study aims to fill that gap by reviewing existing meta-analyses on the impact of these effects within cartography-related disciplines and case studies that test them in the context of map usage. Additionally, a user study is conducted to evaluate a selection of cognitive biases that may affect map reading but have not been empirically tested. The study concludes by synthesizing the findings from the literature review and user testing to provide the first comprehensive list of effects that disrupt logical reasoning in map reading. To theoretically ground the creation of this list, a new concept is introduced: perceptual distortions. This term serves as an umbrella concept encompassing all the effects that could unintentionally influence map reading; it is defined with a broad scope that allows for future phenomena to be tested and incorporated into the list. The impact of perceptual distortions in the context of map usage is an emerging theme with the potential to inform and improve map design principles and thus warrants further research.

Key words: *cognitive biases, optical illusions, perceptual distortions, cognitive science, map reading.*

Resumen

Las investigaciones sobre los aspectos cognitivos de la lectura de mapas se han centrado en cómo la mente humana procesa la información presentada a través de mapas. Sin embargo, esta literatura tiene una brecha en cuanto a

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los fenómenos inconscientes que pueden influir negativamente en el proceso, como los sesgos cognitivos y las ilusiones ópticas. Este estudio tiene como objetivo subsanar esa brecha mediante la revisión de metanálisis existentes sobre el impacto de estos efectos dentro de las disciplinas relacionadas con la cartografía y estudios de caso que los prueban en el contexto del uso de mapas. Además, se realiza un estudio de usuarios para evaluar una selección de sesgos cognitivos que pueden afectar la lectura de mapas, pero que no han sido probados empíricamente. El estudio concluye sintetizando los hallazgos de la revisión de la literatura y las pruebas de usuarios para proporcionar la primera lista compilada de efectos que interrumpen el razonamiento lógico en la lectura de mapas. Para fundamentar teóricamente la creación de esta lista, se introduce un nuevo concepto: distorsiones perceptuales. Este término actúa como una categoría amplia que contiene todos los efectos que podrían influir involuntariamente en la lectura de mapas; se define con un alcance extenso que permite que futuros fenómenos sean probados e incorporados a la lista. El impacto de las distorsiones perceptuales en el contexto del uso de mapas es un tema emergente con el potencial de establecer y mejorar los principios de diseño de mapas, por lo que amerita investigación adicional.

Palabras clave: *sesgos cognitivos, ilusiones ópticas, distorsiones perceptuales, ciencia cognitiva, lectura de mapas.*

1. Introduction

The cognitive turn in the mid-twentieth century had a significant impact on cartography, bringing questions of how the mind processes information during map reading to the forefront (Montello, 2002). Matters such as using different types of symbols, layouts, and colors were thoroughly researched to find the optimal ways of conveying information through maps. Nevertheless, there has been a significant oversight in this field: understanding the various scenarios in which maps do not function as the cartographer intended. Other disciplines that study human behavior have noted that reading and comprehension processes are influenced by unconscious patterns that often lead to unintended consequences: a narrowed focus on a specific portion of the data, a limited selection of remembered features, and a misinterpretation of the information (Miller, 2003). Recent research papers have examined the role of several factors that influence map readers. Nevertheless, these efforts have been scarce and limited by a narrow scope that does not discuss further the findings within the body of knowledge of cognition and cartography.

In the following sections, this paper reviews cognitive science theories to understand the philosophical, psychological, and physiological bases of these patterns and how they cause deviations from a rational and logical interpretation of maps. Drawing on previous research on the impact of biases in information visualization, it proposes a selection of effects that could potentially relate to map reading. The study then proceeds to an experimental component. A methodology for studying the impact of biases compares how users respond

to map designs that explicitly intend to trigger the effect with counterparts elaborated using modern map-making guidelines. The study results are then analyzed using statistical methods to discern if the selected effects have the expected impact. The concluding remarks synthesize the state-of-the-art knowledge about the impact of different distortions on map reading.

2. The study of the role of cognition in map reading

Over the past century, the theoretical foundations of cartography have undergone continuous shifts; historical revisions on the discipline's evolution highlight that some dominant theories, referred to as paradigms, represent the main epistemological tendencies of the discipline. This view is based on the theory proposed by Thomas Kuhn (1996). Key authors in the theoretical realm of cartography agree on the main paradigms for the discipline: communication, analytical cartography, scientific visualization, and critical cartography (Fernández & Buchroithner, 2013; Fairbairn *et al.,* 2021). For the context of this research, it is essential to understand the theoretical grounds of the communication paradigm, which incorporates the cognitive turn. This paradigm considers maps primarily through the lens of communication theory. Within this model, the map serves as a graphic language tool, designed by the cartographer to convey a message to the reader, codifying spatial information through cartographic language. To make this communication straightforward and efficient, practitioners of this paradigm have pioneered user testing research to determine the best mapping practices for text, symbols, colors, and other elements.

The communication paradigm experienced a decline in the 1960s, as other contemporary visions of cartography took precedence, primarily overshadowed by the scientific visualization paradigm (Antle, 1999). Cognitive questions were revitalized within this new paradigm, influenced by the rise of cognitive science in the 1980s (Montello, 2002). With the decline of positivism, emerging theories shifted away from the notion that the human mind objectively comprehends reality. Instead, the new research agendas suggested that the mind constructs representations of it. This additional layer between reality and perception allows for questioning established notions regarding a rational user. The new theory posits that the user's mind perceives the world through sensory input and constructs mental models that relate to reality but never perfectly replicate it. Within the framework of cognitive science, phenomena such as biases and illusions become central to understanding how the mind's representations may differ from objective reality. The next chapter will explore the historical development of these concepts.

3. Patterns of cognitive deviance when observing information

The philosophical debate regarding the relationship between perception and the human mind's interpretation of information can be traced back to the origins of Western philosophy in ancient Greece. Heuristics (*eurisko*) refer to humans' mental processes to solve problems and learn about the world (Hjeij &

Vilks, 2023). The concept has been relevant to epistemic theories for centuries, as it expresses the distinct methods by which new knowledge is created in philosophy's different schools of thought. However, in the 1970s, this concept suffered a significant shift. The psychologists Kahneman and Tversky led a series of experiments demonstrating how heuristics often fail and lead to deviations in how people process information (Rachlinski, 2008). They named these deviations cognitive biases (Kahneman & Klein, 2009). This concept explains how distinct patterns emerge in which mental processes are tainted; readers' interpretation, memory, and attention abilities can be influenced differently when these effects are triggered.

Since the introduction of this idea, research on biases has significantly expanded. Several fields that focus on human behavior, such as psychology, marketing, and design, have conducted extensive studies, resulting in the discovery of many types. With the sudden rise in studies conducted on the subject, tracking the constant developments and maintaining a panoramic view has become very difficult. For this reason, several projects to develop taxonomies began classifying the biases according to different criteria. Some categorizations could be grouped by the heuristic applied that would trigger them; in other cases, they would be classified by the impact they have on the subject. Specific taxonomies were also elaborated in disciplines where biases became a central concept. For the scope of the present research, it is essential to discuss the ones related to information visualization, a field closely related to cartography. This discussion will be elaborated upon in the next section.

Another critical category to discuss is optical illusions (Todorović, 2020). These deceptive effects often manifest as images that deceive human vision and alter the perception of the material world. The most significant difference between them and cognitive biases is that illusions exist in contrast to a verifiable reality that directly clashes with them. While cognitive biases also have a tension with reality, the deviation they produce in the observer is more nuanced than the stark disparity between the illusion and the faithful truth. Another difference between the concepts is that cognitive biases occur in various scenarios. The biases referred to in this research are related to data reading; however, other biases can occur in diverse settings and everyday tasks. In contrast, illusions occur when viewing specific visual patterns.

Within the discipline of cartography, research on both concepts has primarily focused on testing singular effects with a narrow scope, without placing the findings within a broader theoretical context. For this reason, a new concept is introduced into the field of cognitive cartography: perceptual distortions. A team of psychiatrists proposed this idea in computer science (Nour & Nour, 2017). These researchers argue that observing as a medium of obtaining knowledge from material reality is a two-way process in which sensory information travels from the eyes to the brain. Still, there is also a simultaneous flow in the opposite direction, from the brain to the eyes. The cornerstone of this process is the interplay between what is visually perceived and what the mind expects that visual experience to be. This constant interaction gives the observer the impression

of a wholly integrated reality, in which objects and features are identifiable despite being only partially perceived. This act of the mind's 'completing the picture' opens the door for wrong impressions and misinterpretations, such as biases and illusions. Both of these concepts align with the model of perceptual distortions, as they occur when the mind makes inferences based on the available visual data. Still, they create skewed impressions and deviate from the available information. This concept can serve as an umbrella idea encompassing the various phenomena that alter visual information processing when observing maps. The following section summarizes both the cognitive biases and optical illusions that have been tested and proven in the context of map-reading.

4. Cognitive biases and optical illusion studies in cartography

A pair of studies examined cognitive biases in the context of map use. The most well-known one is the Weber-Fechner law, which stipulates that the human eye perceives differences in symbol size on a logarithmic scale, not a linear one (Harrison *et al.*, 2014). This law is a well-established principle in graphic design, having received wide recognition and broad acceptance, and is now part of authoritative guidelines on map design. This law demonstrates that human vision is not sufficiently precise to detect small changes in size, making it necessary to exaggerate these differences to convey information effectively. Another cognitive bias examined in cartography is familiarity bias (Lloyd & Patton, 2011). Researchers have demonstrated that observers concentrate on specific areas, such as known locations and optical central points, and map regions with clustered features. This increased focus on particular areas leads to asymmetries in spatial comprehension, as these locations become more familiar to individuals than others. People can also estimate distances within these focal points more accurately, resulting in a reduced amount of interest in less familiar areas.

Two optical illusions have been tested in a map-reading context: the Müller-Lyer illusion and the Terrain Reversal effect. In the case of the former, researchers developed an experiment in which participants were asked to estimate the distance between two cities, drawn on a map and connected by a road (Gillan *et al.*, 1999). When participants observed the road surrounded by inward-facing lines, they estimated the distance between towns to be shorter than it actually was. In contrast, when the road between the cities is framed with outward-facing lines, the distance appears to be longer than in reality. The second optical illusion triggered in map usage is the Terrain Reversal effect (Çöltekin & Biland, 2019). This illusion occurs when a terrain visualization is perceived in an inverted manner, so that peaks are perceived as valleys and vice versa. The maps' orientation can cause this phenomenon, as the reader's familiarity with the area and the visual style of the terrain representation, with shading and tints.

Studies of optical illusions require controlled environments with specific methodologies designed to address each of the individual effects. For this reason, these kinds of effects were not chosen for the user testing phase. Only cognitive biases were selected for the study. In the next section, the process for choosing the cognitive biases is explained in detail.

5. Potential cognitive biases that could impact map-reading

5.1. Existing taxonomies for biases in information visualization

A review of existing taxonomies was conducted to find potential biases that could be tested and determine if they impact map reading. For this study, the categorizations used in the adjacent field of information visualization discipline were chosen as a starting point due to the proximity of the disciplines. Researchers led by Dimara conducted an extensive literature review, identifying the degree of relatedness between cognitive biases and information visualization (Dimara *et al.*, 2020). They achieved this by conducting a systematic meta-analysis of empirical studies that evaluated the impact of these biases and analyzed which aspects of the cognitive processes involved in information visualization could be influenced by them. Their taxonomy consists of two parts. On one level, they classified all the biases into the type of effect they have on subjects, establishing seven different kinds. On another level, they assigned scores to the biases based on the results of experimental studies and ranked them according to their level of relatedness to information visualization.

Researchers led by Calero Valdéz created another relevant taxonomy (Calero *et al.*, 2018). They propose a different classification, categorizing biases by the moment they occur during the cognitive process of information processing, theorizing three distinct moments. The first one is perceptual biases, which occur at the lowest level of perception; at this point, optical input is prone to misjudging visual information due to priming, which is the innate habit of the human mind to associate present experience with memories. In the next phase of perception, action biases occur when sensory input has been processed, and the brain decides which actions to take accordingly. The last level is social biases, which occur when perceptual input is placed in a broader societal context, and individuals employ rationality to make sense of their perception. These two taxonomies served as the starting point for filtering out the possible biases that could be studied in the context of map reading. The process of selecting biases for a user-testing experimental design is outlined in the next section.

It is essential to note, however, that there might be effects outside the taxonomies that have been documented; however, it remains unclear what kind of phenomena they are. That is the case, for example, of the dark-is-more bias, in which darker colors are systematically associated with higher quantitative values (Matzen, 2025; Schiewe, 2019, 2024; Sibrel *et al.*, 2020). It is referred to as a bias in the literature; its effect is well-documented, but its functioning as a bias remains unclear. It could be possible that associating darkness with

higher values is a learned convention rather than an innate cognitive pattern. Due to these doubts and the fact that it has not been included in the consulted taxonomies, it was not further considered in this study.

5.2. Selecting biases with the potential to influence map-reading

The process of narrowing down the possible biases began by selecting the ones that had already been shown to be related to information visualization, according to the scores assigned by Dimara *et al.* (2020). They began with a comprehensive list of 170 biases, then narrowed it down to 150, for which they could find sufficient scientific evidence. They ranked them in eight levels; at the highest level, the biases were proven to be related to information visualization; at the lowest level, they classified those that showed unclear relevance to the field. Based on these criteria, only biases at level four and above, which include all effects with evidence and those that are likely relevant but have not been empirically tested in information visualization, were considered for the experimental phase of this research.

This selection narrowed down the number of possible biases to 73. Now, based on the theoretical criteria of the taxonomy proposed by researchers led by Calero Valdez, a subset of biases was further elaborated upon (Calero *et al.*, 2018). Only the effects of the first two levels of perception were considered. Even though social biases may still be relevant in map reading, a highly controlled environment and a specific approach are required to study each social bias, as they require consideration of individuals within their cultural and social contexts. For this reason, social biases were also excluded, but eliminating them was not a straightforward process, as the taxonomy led by Calero Valdez does not provide a thorough classification of every effect. To identify these biases, further considerations were elaborated upon based on the analysis led by Dimara, as this is a more exhaustive and detailed categorization.

In the taxonomy led by Dimara, there are two levels of categorization for biases independent of the ranking above. First, they established seven typologies of how biases affect information visualization. Two categories of biases, those affecting opinion reporting and decision-making, were considered to have a substantial social component due to the effects associated with perception within a social context. For that reason, they were excluded from further analysis. Then, they also established flavors, subcategories of biases that reflect other similarities and touch upon how they affect cognition, rather than which kinds of tasks they impact. Within this categorization, there are two types of biases: those that act through association and inertia, which can be considered social biases and are thus discarded from further consideration. The association biases occur when cognition is affected by tainted connections between known information and new data being observed. Inertia biases act by influencing or confirming knowledge that is already established before new data is observed. In these two cases, cognitive mishaps occur when the observer contrasts their current perception with their existing knowledge, and they can be considered to enter the social scope.

After applying this filter, 35 biases remained under consideration. To find suitable candidates, only effects that can be considered to have a significant connection to visual communication were considered. Some of the biases on the list operate through different cognitive processes, such as probability estimation, processing information in lists, and processing memories. Since these biases do not occur primarily through visual stimuli, they were not considered in this study. An analysis of these considerations is elaborated upon in the following Table 1, where the remaining biases are briefly explained, and their primary focus, whether visual or other, is established. The definitions for the biases are taken from the taxonomy led by Dimara (2020).

Table 1. Pre-selection of biases for empirical testing

Bias	*Description*	*Main Focus*
Anchoring	Estimation by first piece of information	Deals with memories
Availability bias	Events are more probable if they are easy to remember	Deals with previous memories
Base rate fallacy	Ignore base rate probability of general population	Based on numerical reasoning
Bizarreness effect	Easier to recall bizarre items	Possibly map-reading related
Clustering illusion	Seeing patterns in noise, e.g., clusters in a dot field	Possibly map-reading related
Confirmation bias	Favor reasoning that confirms preferred hypothesis	Deals with memories
Congruence bias	Seeking confirmation for the preferred hypothesis only	Focuses on creation of arguments
Conjunction fallacy	Specific outcomes more probable than general	Based on numerical reasoning
Cue-dependent forgetting	Failure to recall without memory cues	Deals with memories
Dunning-Kruger effect	Low-ability people overestimate performance	Focuses on self-evaluation
Exaggerated expectation	Exaggerating evidence to fit a conclusion	Focuses on argument creation
Gambler's fallacy	More frequent outcome seen as less frequent in the future	Based on numerical reasoning
Hindsight bias	Recall past predictions as more accurate after the outcome	Deals with memories
Hot-hand fallacy	More frequent outcome seen as more frequent in the future	Based on numerical reasoning
Illusion of validity	Overconfidence in intuition-based judgments	Focuses on self-evaluation
Illusory correlation	Perceived relationship between unrelated variables	Possibly map-reading related
Illusory truth effect	Repeated statements considered more accurate	Deals with memories

Continue Table 1

Bias	*Description*	*Main Focus*
Information bias	Seeking irrelevant information	Focuses on argument creation
Insensitivity to sample size	Estimate probability ignoring sample size	Based on numerical reasoning
Leveling and sharpening	Recall sharpens some features, weakens others	Happens when hearing stories
Levels of processing effect	Easier recall after deep-level analysis	Possibly map-reading related
List-length effect	Harder recall with longer lists	Happens in lists
Modality effect	Better recall of auditory than visual information	Not studying auditory stimuli
Ostrich effect	Avoiding negative information	Possibly map-reading related
Pareidolia	Seeing faces in noise (e.g., toast)	Possibly map-reading related
Part-list cueing effect	Harder recall after reexposure to subset	Deals with memories
Picture superiority effect	Better recall for images than words	Possibly map-reading related
Planning fallacy	Overoptimistic task completion predictions	Focuses on self-evaluation
Processing difficulty effect	Better recall for hard-to-understand info	Possibly map-reading related
Regressive bias	Overestimate high and underestimate low probabilities	Based on numerical reasoning
Serial-positioning effect	Best recall for first and last items in a list	Happens in lists
Subadditivity effect	Overall probability less than the sum of parts	Based on numerical reasoning
Time-saving bias	Overestimate the time saved by increasing speed	Focus on transportation
Von Restorff effect	Better recall for distinct items	Possibly map-reading related
Weber-Fechner law	Failure to perceive slight differences in large quantities	Possibly map-reading related

This research will explore specific biases related to visual communication, including the clustering illusion, illusory correlation, the ostrich effect, the processing difficulty effect, and the Von Restorff/Bizarreness effect. Other phenomena, which showed promise, were nevertheless excluded from the study for several reasons. The levels of processing effect, in which people can better recall information that results from deep levels of analysis (Craik & Tulving, 1975), requires an overly specialized research design and knowledge of participants' interests, as they tend to focus on these aspects. Pareidolia, an effect that causes people to perceive familiar shapes in unrelated images

(Voss *et al.*, 2012), could potentially be present in map reading; however, it occurs too spontaneously and sporadically to be studied meaningfully. The picture superiority effect, which makes information displayed in images more memorable than other media (McBride & Anne Dosher, 2002), proves difficult to isolate since maps inherently combine images and text. The Weber-Fechner law, which describes the logarithmic perception of size differences, is, as mentioned earlier, already well-established in cartography, making further experimental validation less of a priority.

6. User study methodology and results

6.1. General considerations

The user study compared how users read map information in two sets of maps, one based on modern map-making guidelines, and the other was specifically designed to trigger the selected biases. In this case, a map-making guide published by the United Nations was used as a reference (Kraak *et al.*, 2020). In a web-based survey, participants were shown either the standard design or the bias-inducing map using the A/B testing method (Gallo, 2017); they were randomly assigned to the map versions. Then, the contestants answered a series of map interpretation questions to determine if the changes in design produced measurable differences compared to a standard-designed map. The maps were created using fictional data from OpenGeoFiction to avoid preconceptions about different regions influencing the results.[1] Additional dummy data and questions were also added to avoid user training.

The experiment was created by designing standard and bias-inducing maps. The prototypes for these maps were developed by interpreting the biases and translating them into a visual language that would trigger the effects. Experts in cartography later validated these proposed maps through a survey, in which participants were asked about the soundness of the approach. The feedback led to further adjustments in the designs.[2] The experiment for users was designed to test biases consistently; they were restricted from using the back-page button throughout the survey, and in most cases, they had a fixed time to observe the maps. The maps were elaborated with fictional geographic information and dummy datasets to avoid users' previous perceptions of the world interfering with the study results. The following subsections will discuss the proposed designs for studying the selected biases and their results.

1 OpenGeoFiction is a platform similar to OpenStreetMaps with volunteered geographic information, but in this case, it is entirely fictional (OpenGeofiction Contributors, n.d.).

2 The survey and the results of the consultation with experts for the designs can be found on the server of the ITC institute of the University of Twente (https://kartoweb.itc.nl/msc-carto-thesis/materials/nicolas_martinez_heredia/).

6.2. Demographic profile of contestants and statistical methods of analysis

The survey had 174 contestants recruited from survey forums and social media.[3] Since the survey was distributed across digital channels, the sample is skewed towards younger individuals (with an average age of 38.54) who frequently use computers. Most contestants were from Europe (48.9%), North America (27.9%), and South America (12.6%). In terms of gender, the majority of participants were male (51.7%). Four statistical tests were used in the analysis to discern the results: the Chi-squared test, Fisher's exact test, the Mann-Whitney U test, and the T-test. A significance level of 0.05 was established as the threshold to determine the success of the experiments. These four statistical tests were selected to analyze the study's data types and experimental conditions. The Chi-squared and Fisher's exact tests are used for categorical data to determine if observed patterns differ significantly from what would be expected by chance (McDonald, 2017, 2019). Fisher's exact test is preferred when sample sizes are small because it provides more precise p-values. T-tests are employed when comparing the means of two groups with normally distributed continuous data, such as measuring differences in performance between control and experimental conditions (Navarro, 2019). Mann-Whitney U tests serve as the non-parametric alternative to t-tests, used when data do not meet normality assumptions or when dealing with ordinal or binary distributions, ensuring robust statistical analysis regardless of the underlying distribution (Webb, 2023). Together, these tests provide comprehensive coverage for the variables used in the study.

7. Biases tested and results

7.1. Clustering illusion

The Clustering illusion occurs when people misidentify nonexistent patterns in random data distributions (Albert *et al.*, 2018). To trigger this bias, a randomly generated point dataset was displayed at different scales. While the standard map (Figure 1) was designed to maintain an optimal visual balance and avoid oversaturation, the bias-inducing version (Figure 2) employed a high level of detail to expose the reader to more local patterns, thereby allowing viewers to mistake local variations for general trends. The created maps show the distribution of a plant species across the administrative divisions. The number of points generated was proportional to the size of each state, so the density of points is constant across the country; the position of the points is randomized.

[3] The user study survey, the whole dataset with the results, and Python scripts of the data analysis can be found on the server of the ITC institute of the University of Twente (https://kartoweb.itc.nl/msc-carto-thesis/materials/nicolas_martinez_heredia/).

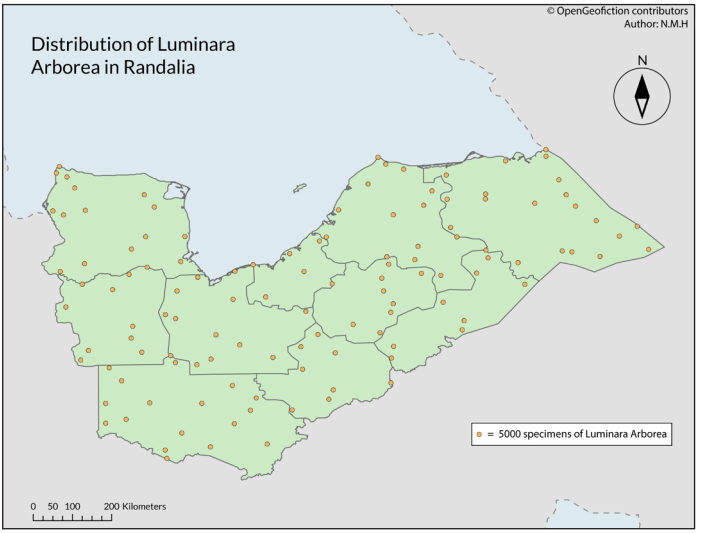

Figure 1. Standard map design (Clustering illusion).

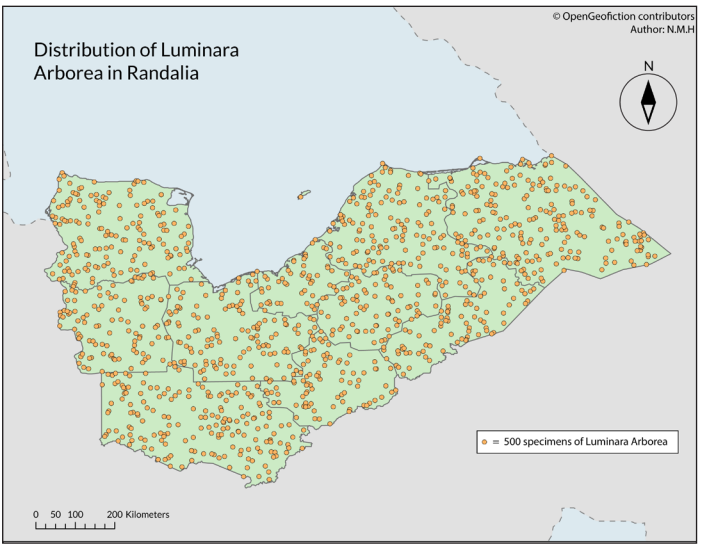

Figure 2. Bias-inducing map design (Clustering illusion).

The contestants were asked: *Which states had a higher density of points than the rest? The correct answer was: no states had more point density.* The percentage of correct answers was compared for the control group and the contestants who received the bias-inducing version of the map (Figure 3), showing that more contestants were able to identify the correct distribution in the bias-inducing group; the difference was statistically significant (Fisher's exact test; Odds Ratio

= 0.257, p-value = 0.0000288; Chi-squared test; $\chi 2$ = 16.31, p-value = 0.0000538). These results contradicted the hypothesis. The higher density caused better, not worse, map-reading performance; therefore, the hypothesis is rejected. These results suggest that the perception of point densities does not operate as expected. A possible hypothesis for why this occurred is that when the density of points is too high, it appears to reach a saturation point, resulting in excessive visual information for the reader. The user will then not perceive any false patterns in the data.

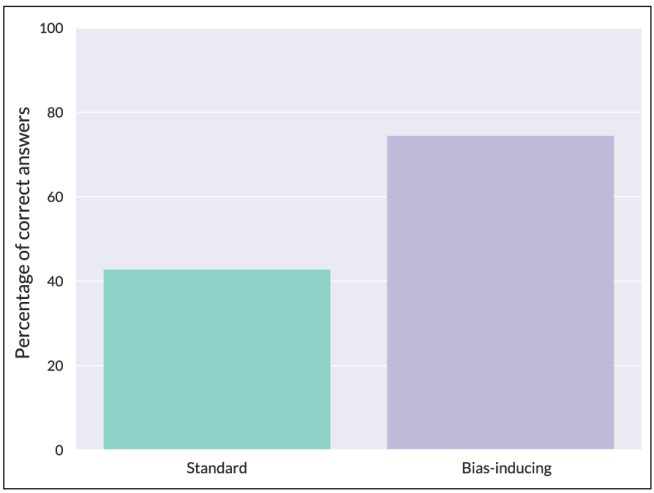

Figure 3. Percentage of contestants that answered correctly in the standard and bias-inducing groups (Clustering illusion).

7.2. Illusory correlation

The Illusory correlation bias causes readers to mistakenly associate events that co-occur, creating a false correlation between them (Halik, 2012). Two random datasets were generated and displayed on a thematic map as a bivariate visualization, utilizing choropleth and graduated symbols to illustrate this bias in a cartographic example (Figure 4). The random generation of the data was controlled to avoid statistical and geographic correlation. In the bias-inducing design (Figure 5), an associative color palette is used in the symbology for the datasets to amplify the psychological connection between the variables. After observing the map, the users had to answer whether they perceived a positive, negative, or no correlation between the datasets.

The contestants were asked: *How would you describe the relationship between the variables? If you cannot remember exactly, make your best guess. The correct answer was no relationship*. The results showed no significant variability (Figure 6) between the control group and the one that received the bias-inducing stimulus (Fisher's exact test; Odds Ratio = 1.119, p-value = 0.865, Chi-squared test; $\chi 2$ = 0.025,

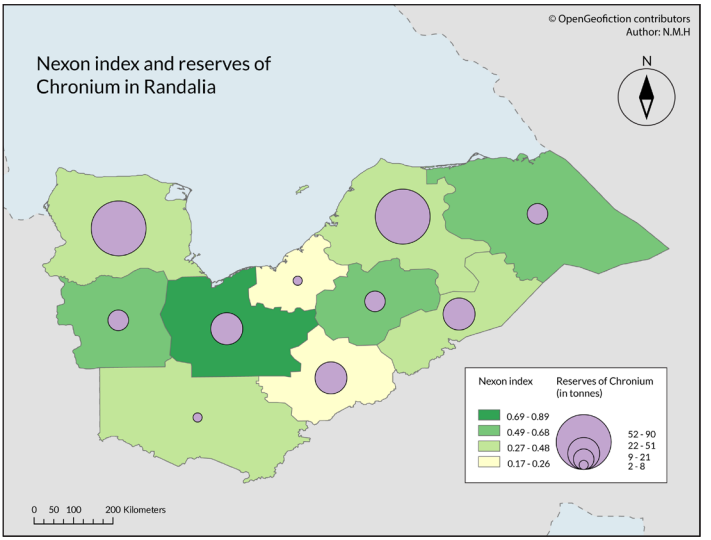

Figure 4. Standard map design (Illusory correlation).

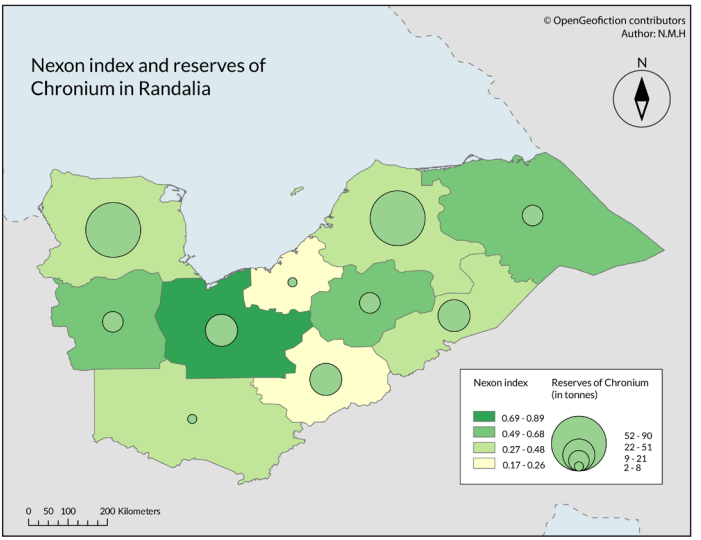

Figure 5. Bias-inducing map design (Illusory correlation).

p-value = 0.875) and are considered inconclusive. These findings show that the proposed design was inadequate in measuring the impact of the bias. To begin with, the problem of Illusory correlation is that any datasets presented together could trigger the effect, as long as they are available simultaneously. This is

why establishing a baseline is a complicated task, which was not resolved in this design. Another potential reason is the problem of map authority (Gregorio, 2022). The perception of maps as sophisticated scientific products in public discourse creates expectations for users; they anticipate that a map will carry a strong argument for the information it presents. It is possible that this expectation mitigated the effect of the bias.

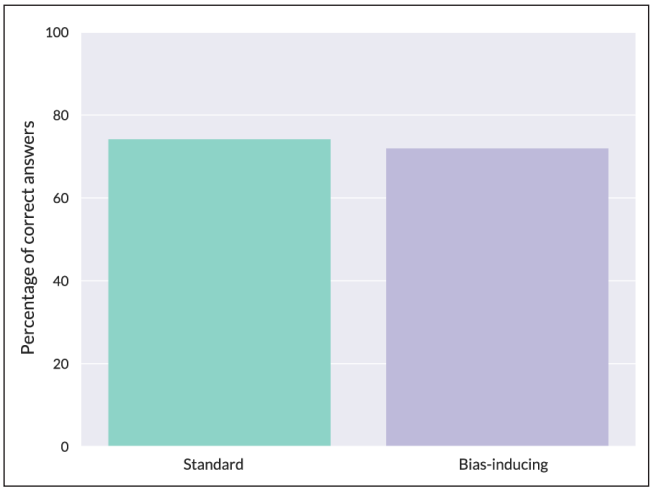

Figure 6. Percentage of contestants that answered correctly in the standard and bias-inducing groups (Illusory correlation).

7.3. Processing difficulty effect

The processing difficulty effect enhances user memory retention as the effort to apprehend data increases (O'Brien & Myers, 1985). To trigger this effect in a map-reading setting, the created maps showed the locations and name labels for cities of the fictional country used for the study. The map, designed according to current guidelines (Figure 7), featured a simple layout that clearly displayed state divisions, city placement, and names. On the other hand, the bias-inducing design (Figure 8) features an additional layer of roads connecting the cities, adding more visual elements and complexity to the map. The proposed hypothesis is that with the added visual elements, the map requires a higher cognitive load to read, making the features more memorable to users. After observing the map, users are prompted to write down the names of as many cities as they can remember. The results were analyzed using the Levenshtein distance algorithm, which matches words according to a specified tolerance. In this experiment, the tolerance was set to 70%, allowing for user errors due to the possibility of typos and the difficulty of remembering unfamiliar words. If the study design is correct, the users who observed the bias-inducing version of the map should be able to remember more city names than their counterparts.

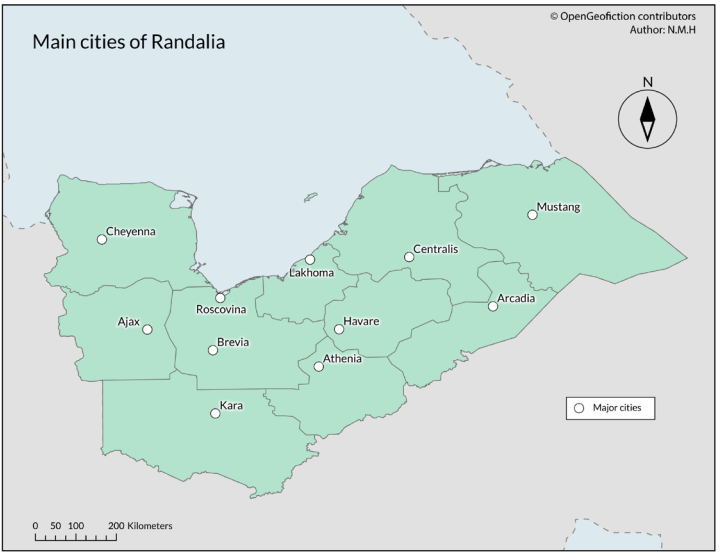

Figure 7. Standard map design (Processing difficulty effect).

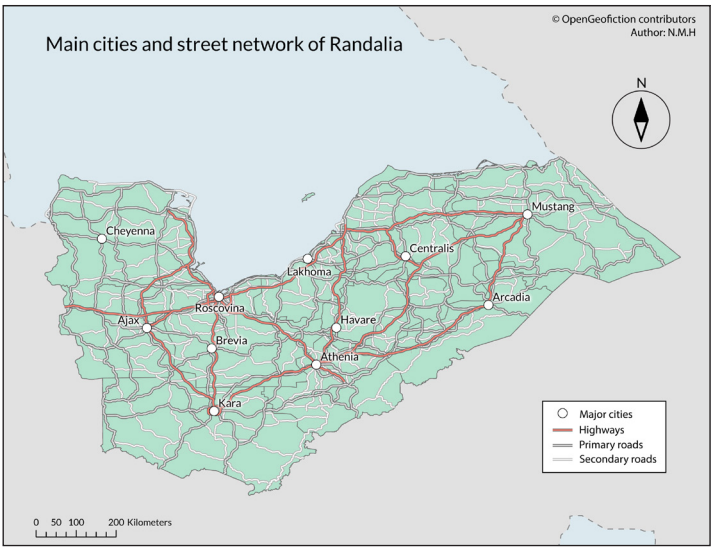

Figure 8. Bias-inducing map design (Processing difficulty effect).

In this case, the results were negative and above the significance threshold (Figure 9); the performance of name recalling was stronger in the control group (T-test; t-statistic = 3.973, p-value = 0.000104). The interpretation of the result shows that usual map-reading contexts favor lower cognitive loads for users. When faced with a task that requires higher effort, users may become

disinterested if there is an insufficient incentive to engage with it. In this case, the higher visual complexity likely deterred users from learning the city names in the first place compared to the control group. The results of this experiment support the prevailing view of map design, which emphasizes minimalism and visual clarity.

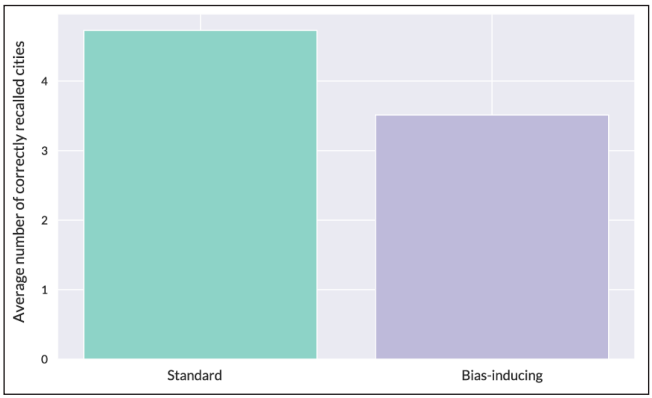

Figure 9. Average number of recalled cities in standard and bias-inducing groups (Processing difficulty effect).

7.4. Von Restorff effect

The Von Restorff effect explains how visually distinct elements grab the attention of human readers (Parker *et al.*, 1998). In a group of visually similar stimuli, one that deviates from the pattern of similarity will attract the viewers' attention. Two topographic maps showing sets of landmarks with icons in a fictional city were created to study this effect. The icons used adhered to cartographic design principles, including consistency and homogeneity (Figure 10) . One of the icons was changed for the bias-inducing version of the map (Figure 11) to make it stand apart from the rest. After observing the maps, the users were asked to remember as many place names as possible. In this case, the changed icon was expected to be remembered more by the users than the other elements.

For the Von Restorff effect testing, the rate at which the altered element was remembered in the control group was compared to that of the group that received the bias-inducing map. In this case, the data shows a result in the positive direction (Figure 12), which means the changed element was remembered more, but the statistical results were narrowly below the significance threshold (Fisher's exact test; Odds ratio = 0.4033, p-value = 0.0688; Chi-squared test; $\chi 2$ = 2.8384, p-value = 0.0920). For this reason, the results are considered weakly positive. Since maps are complex graphical products, multiple confounding factors influence the symbol. Besides the appearance of the symbol itself, the placement of it in the map layout also impacts its visibility; it is known, for example, that elements located slightly above the center of the image are more

salient (Schlosser & GISP, 2024). The meaning of the symbols also influences the reader; in this case, personal preferences related to urban activities could also affect what the contestants remembered for each map. Due to this combination of factors that could interfere with the results, further research is needed to validate the findings of this experiment.

Figure 10. Standard map design (Von Restorff effect).

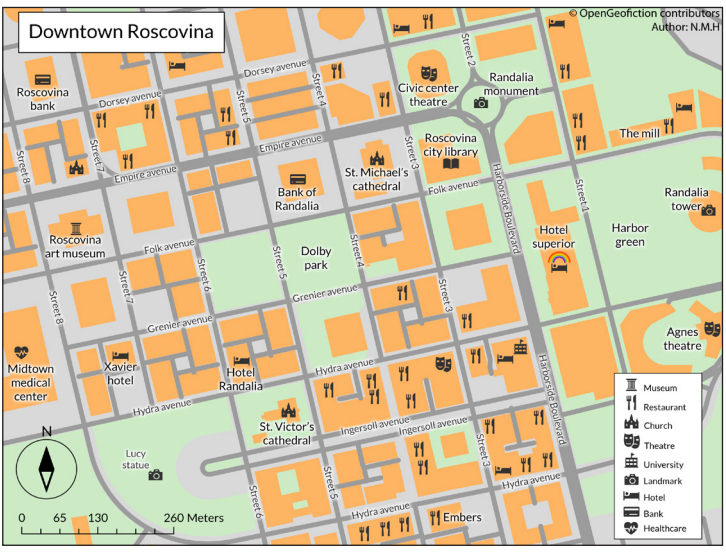

Figure 11. Bias-inducing map design (Von Restorff effect).

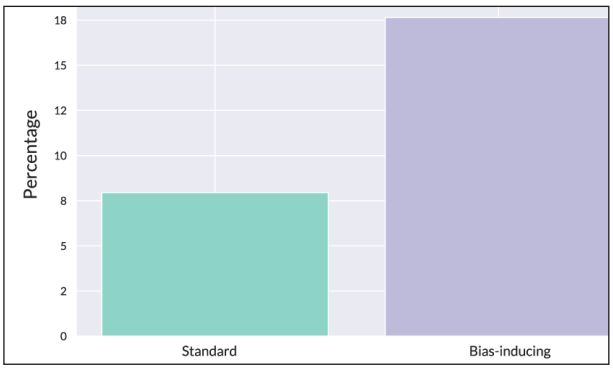

Figure 12. Percentage of contestants who recalled the altered element (Von Restorff effect).

7.5. Ostrich effect

Finally, the Ostrich effect causes people to avoid uncomfortable information, which is often related to adverse experiences, such as illness and death (Karlsson *et al.*, 2009). To explore the reach of this effect in cartography, maps were created showing the levels of a fictional disease and the number of casualties associated with it. The maps differ in their visual language to convey this data; one employs a standardized approach (Figure 13), using neutral colors and abstract symbols. In the bias-inducing version (Figure 14), the visual language emphasizes the negative connotation of the information, using bright red colors to express danger and imagery of skulls to symbolize death. In the specific case of this bias, the way users were tested was not based on questions but on timing how long they observed the map before skipping to the next page. According to the theory, the users would skip the map, which triggers more negative emotions, faster than the other.

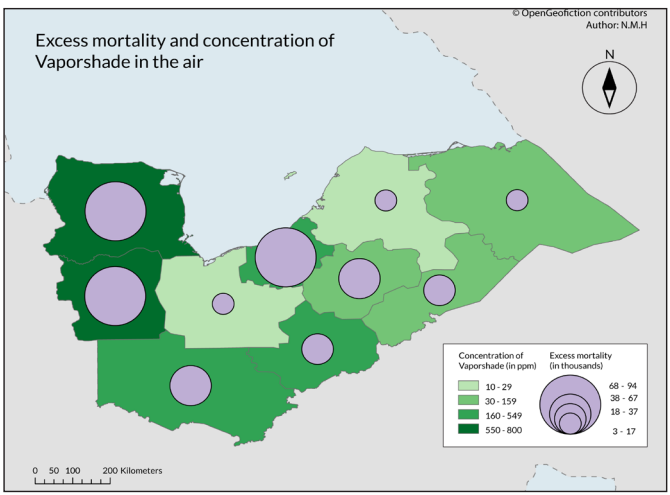

Figure 13. Standard map design (Ostrich effect).

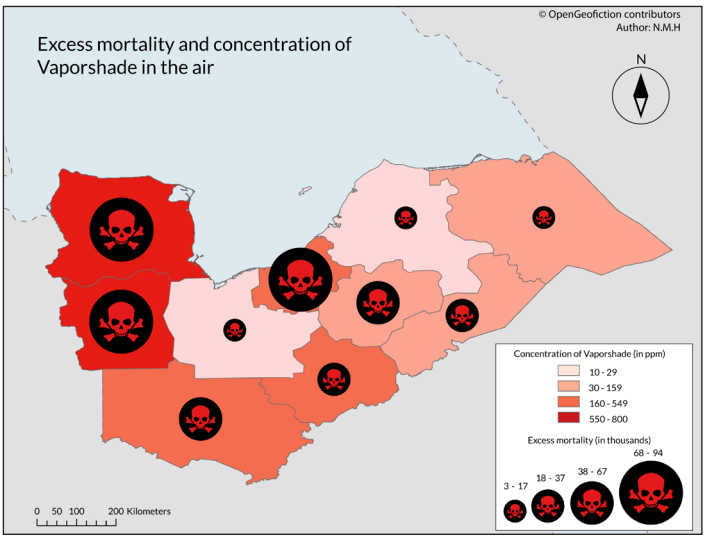

Figure 14. Bias-inducing map design (Ostrich effect).

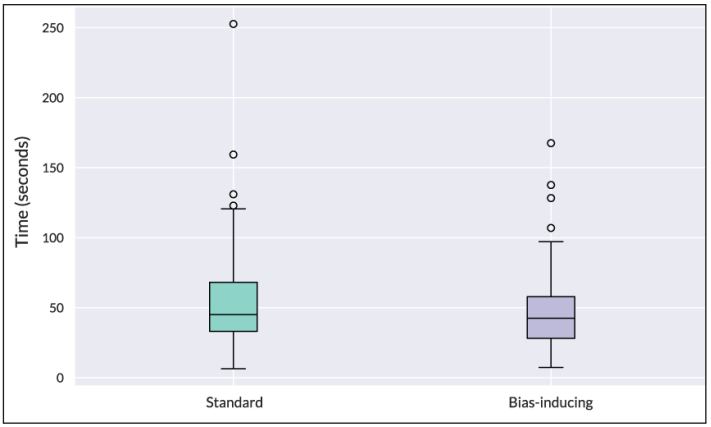

Figure 15. Time spent observing the map by the standard and bias-inducing groups (Ostrich effect).

The approach for the Ostrich effect was markedly different because it involved timing the users as they observed the map. The bias-inducing map version was supposed to be observed for shorter periods due to the negative emotions it triggered. The results of this test were positive and significant when outlier values, which were above or below three standard deviations, were eliminated (T-test; t-statistic = 2.325, p-value = 0.0213). The results confirm that visual language elicits emotional responses that can deter users from actually engaging with the information displayed in the map. The results from this testing

support current map-making guidelines, which advocate for a more neutral and less inflammatory visual language.

8. Conclusion

In summary, this research addressed the problem of understanding, at a conceptual level, how visual information displayed in maps may cause unintended cognitive effects on readers, and then tested a methodology to discern the impact of some of these effects. In the theoretical realm, optical illusions and cognitive biases are key concepts for understanding human deception when encountering visual information. The literature review revealed that a handful of effects have been tested on map reading. Still, no comprehensive theory groups these phenomena and places them within the context of cognition and its role in map reading. For this reason, a new concept, perceptual distortions, is proposed as an umbrella term that can encompass the known effects that impact map reading and future ones that may be discovered. Five effects hypothesized to have a relationship with cartography were tested using a user testing methodology. One showed a strong positive result, while another showed a weak result, which requires further validation. In contrast, the remaining effects had negative or inconclusive results. As a final product of the research, the following Table 2 presents the perceptual distortions related to map reading, including effects previously tested and identified during the literature review, as well as the positive results of the empirical component of the research. As evidenced by the analysis of the results, the study of distortions presents an opportunity to test design standards and gain further insights into how people read maps, making further research to identify additional effects warranted.

Table 2. Perceptual distortions found in map-reading as of today

Perceptual distortion	*Description*	*Hypothesis*
Ostrich effect (cognitive bias)	Avoiding negative information	Positive results in this research show this effect impacts map reading
Von Restorff effect (cognitive bias)	Distinct items are better remembered	Positive result in this research was not significant, so it requires further testing
Weber-Fechner law (cognitive bias)	Failure to perceive small differences in large quantities	Already proven
Müller-Lyer illusion (optical illusion)	Depending on line orientation distance is misjudged	Already proven
Terrain reversal effect (optical illusion)	Landforms are misinterpreted in topographic maps	Already proven

Acknowledgments

This research work was developed as a thesis for the Erasmus Mundus Master's program in Cartography. I want to thank my supervisor, Dr. Florian Ledermann, for his invaluable guidance and support throughout this project. I would also like to give warm regards to Juliane Cron, the thesis reviewer and program coordinator, for her comments throughout the process and for her ongoing support during my studies. I am also grateful to the Pan American Institute of Geography and History (PAIGH) for awarding this thesis the Prize for the Outstanding Master's Thesis in Cartography, Geodesy, and Geographic Information.

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