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Cartographic Redundancy in Reducing Change Blindness in Detecting Extreme Values in Spatio-Temporal Maps

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Abstract: The article investigates the possibility of using cartographic redundancy to reduce the change blindness effect on spatio-temporal maps. Unlike in the case of previous research, the authors take a look at various methods of cartographic presentation and modify the visual variables in order to see how those modifications affect the user's perception of changes on spatio-temporal maps. The study described in the following article was the first attempt at minimizing the change blindness phenomenon by manipulating graphical parameters of cartographic visualization and using various quantitative mapping methods. Research shows that cartographic redundancy is not enough to completely resolve the problem of change blindness; however, it might help reduce it.

Keywords: animated map; cartography; change blindness; user testing; visual perception

1. Introduction

Cartographic animation makes it possible to present spatial and temporal changes simultaneously. Even though technological progress has moved animated maps into the realm of the Internet and enabled users to view them in an interactive fashion, their perception is still problematic. As aptly noticed by [1], the problem with animated map perception is not caused by the technology itself, but rather by the limited perceptual capabilities of the user. Many researchers are of the opinion that the problem in question stems from the dynamic nature of such a kind of presentation [2,3], which requires the user not only to perceive the changes occurring on the map, but also to estimate their volume and the moment when they occurred [4]. However, technologies have dramatically changed and D3.js and various map APIs allow us to develop much better maps nowadays with different timeline design options [5,6].

We believe that changes occurring on animated maps might vary depending on the nature of the particular change (appearance, disappearance, movement, etc.), but also on the mapping technique [7,8]. As various mapping techniques are based on various visual variables, they generate various kinds of changes. Changes taking place on animated maps are susceptible to a perceptional problem known as change blindness. It is a phenomenon whereby a user fails to notice a change occurring in the form of a visual stimulus [9,10] It occurs during the transition from one image to another. If the two images differ from each other, the difficulty lies in the visual perception of those changes. Bearing this in mind, we set out to study the perceptual limitations of the animated map user, taking into consideration various mapping methods.

The paper focuses on comparing three mapping methods in terms of their perception by the users. The techniques chosen to be studied included: proportional symbol map, line symbol map, and choropleth map. They vary in terms of the geometric types (points, lines, and areas), i.e., the basic elements used for presenting geographic space (not only in digital cartography; also in traditional, old maps) [11]. The proportional symbol map features point objects and uses their size to illustrate the intensity of the geographic phenomenon [12] (p. 324). The line symbol map employs line symbols and computer animation to present movement from one location to another. The speed of movement is set by manipulating the dynamic variables [13], while the direction, path, and intensity are presented using a line of proper width or color [14] (p. 149). The last of the techniques chosen to be studied was the choropleth map, featuring areas (often corresponding to administrative units), with color or texture presenting the intensity of the phenomenon within those areas [15] (p. 120).

The three mapping methods were studied in the context of a problem that applies to them all—namely, change blindness. The phenomenon consists in failing to perceive changes in a changing image [16,17]. Perception is based on visual stimuli which are generated by visual variables [18]. So far, researchers have managed to draw some conclusions on the connection between change blindness and visual variables. However, they are still incomplete, as many aspects of cartographic design are yet to be adequately studied in the context of user perception [19,20].

Thematic animated maps make use of visual stimuli to present geographic information. We believe that it is important to find such a combination of stimuli that would work best to reduce perceptual problems. Studies on searching for the right visual stimuli have testified to a particular importance of two visual variables—size and color [21–23]. There is evidence that redundancy/highlighting improves the effectiveness and speed of map reading, both of which are lowered when change blindness occurs [24]. Strengthening the visual cue by using those two variables might be the key to improving the perceptibility of objects displayed in the course of the animation. The main objective of this paper is to answer the following research question: does strengthening the visual cue via a redundant change of size lead to an increase in the detectability of extreme values of a phenomenon on an animated map?

The paper addresses perceptual problems connected with animated cartography. We begin by discussing animated maps in terms of their design and the perceptual problems encountered by their users, on the basis of the existing literature. We also describe the significance of change blindness in reading animated maps. Next, we proceed to demonstrate how we designed the maps to be used in the study. Based on those animations, the participants would complete tasks requiring them to notice maximum and minimum values on the map and on the timeline. Then, we describe the participants and the course of the experiment; finally, we present the results and discuss them in view of the current state of the art. In the summary, we state advantages and disadvantages of the conducted experiment and point out research challenges regarding change perception in animated cartography.

2. Animated Map and Visual Perception

This chapter addresses problems of visual perception in animated cartography. We will review the existing literature in search of the reasons behind change blindness and methods of preventing it.

2.1. Characteristics of Animated Maps

Animated map is a cartographic image which presents in a dynamic manner the changes affecting a geographic phenomenon [25,26]. Changes taking place on the map do not necessarily have to be of a temporal kind. Lobben [27] has distinguished between several kinds of cartographic animation, with the changes affecting space, time, and visual variables. Animations in which there is a change in space, but time and intensity remain unchanged, are defined as "areal animations". Here belong the so-called fly-by animations, where the viewing point of the object changes dynamically at a specific moment in time [28,29]. Another type of animation is the "process animation", which might illustrate movement of a phenomenon and the direction in which it spreads. Animations might also be limited to a change in phenomenon intensity within a fixed space. They are then called "thematic animations", and employ visual variables to present the appropriate values of the phenomenon in consecutive time frames. In the case where space remains fixed, and the only element undergoing changes is the location or presence of the phenomenon, we are dealing with "time series animation".

Research on animated maps has yielded interesting conclusions about their effectiveness. It turned out that cartographic animations present perceptual challenges for the viewers [1,30,31]. This is due to the fact that in animated maps, the change in phenomenon intensity occurs in multiple places at the same time. In the case of the proportional symbol map, attribute change is shown through changing size of the point; in the choropleth map—through changing the color. Hence, attribute changes are reflected in changes affecting the visual variables. Because they occur in multiple places on the map simultaneously, there is a risk that the user might not notice all the values of the presented phenomenon. While viewing the south-western fragment of the map, they might overlook changes occurring in the north-eastern fragment, due to their distance on the map from the point being viewed [2]. Focusing the attention on a single spot generates problems in perceiving the surrounding area and attentively viewing multiple spots at the same time [32]. Although principles of the proper design of animated maps are an attempt at addressing such perceptual problems [33], the available scientific knowledge is still insufficient [20,34].

A crucial element in animated map design is the appropriate choice of parameters for the dynamic variables. Even though this aspect is a key one in cartographic animations, not much attention has been given to its role in the context of change blindness. If the animation is too fast, the user is not capable of noticing and memorizing all the map symbols displayed. On the other hand, displaying a single image for too long creates an impression of a lack of any changes [35]. An appropriate grading of change intensity via magnitude of change makes it possible to obtain an animated map that is easier in interpretation, and consequently, more effective [19].

The main goal of animated mapping is to present changes in time and space [27]. Geographic processes can either be temporally continuous or discrete, which might be reflected in the animation through two alternative transition modes. The first one consists of displaying time series or showing a sequence of static images, creating an impression of the passage of time. This might be achieved by using satellite or aerial images of the same area taken at various times [36]. The other mode is the use of a smooth transition (tween) to illustrate the change. Such a transition means that the visual variables are modified in a continuous fashion, which reflects the changing intensity of the geographic phenomenon [37]. Despite a few studies on the effects of using smooth vs. abrupt transitions, there is no agreement as to their impact on reducing change blindness. It is suggested [38] that the use of smooth transitions is conducive to drawing the user's attention to the occurring changes [39], on the other hand, claims that such a transition might hinder the proper perception of a visual stimulus such as color. It was [19] who noticed that it is the overly long time of the smooth transition on the animated map that prevents the user from perceiving changes, which had already been noted before in the field of visual analysis [40]. An affecting users searching for changes in an animation featuring a smooth transition of colors is presented in the link. Is it therefore possible, as far as change blindness is concerned, to use smooth transition equally effectively not only with color, but also with other visual variables?

2.2. Change Blindness

Change blindness is a phenomenon whereby a user fails to notice a change occurring in the form of a visual stimulus [9,10]. In the case of an animated map, it means that the user does not notice a change in the size or color of a cartographic sign which represents phenomenon intensity. This might be caused by a number of reasons. First, it might result from eyeball movement—a short blink or sight shift to another area [41]. Another reason might be an overly complicated image or an excessive number of visual stimuli [42]. Moreover, the change that took place might not have drawn the attention of the user to a sufficient extent as to be noticed by him/her [16]. When the user's attention is focused on one area, changes occurring in others might pass unnoticed [43]. This is connected with the split attention effect, which takes place when the user tries simultaneously to perceive changes taking place on the map and the ones occurring on the temporal legend. Some researchers point out that a map featuring many different kinds of changes is more complicated for the user and might cause him/her to experience perception problems [44,45]. There are also doubts regarding the use of interactive tools—they, too, might be a source of distraction [46].

Taking into account the limitations of the map user's working memory, the number of classes should be limited to seven, give or take two, in accordance with Miller's principle [47]. However, animation makes it possible to notice simultaneous changes in four or five places at most [42]. In spite of that, animated maps tend to feature many more points or administrative units undergoing simultaneous changes. For that reason, research on reading animated maps is usually limited to small areas, and the users are informed where they should focus their attention [1]. This approach is criticized, however, as actual cartographic animations tend to be much more complex [19]. Besides, limiting the study to only one type of animated map is an oversimplification, as animation might be applied to various mapping methods, which may affect the user's perception in varying ways.

Focused attention allows the user not to overwrite the memory of the stimulus pattern. If the visual cue is too weak, it prevents the user from noticing the change [16]. It has to be strong enough to break through the background noise [48]. In the context of animated maps, this means that the modification applied to the visual variable must be big enough for the user to notice the change between the two states, and there must be sufficient contrast for the sign to be distinguished from its surroundings. The process of noticing the change involves stating whether the change occurred, what was its degree, and where it occurred. In the case of animated maps, another important aspect (though not always taken into account) is when the change occurred.

3. Design of Animated Maps

For our study on animated map perception, we chose three types of thematic maps: proportional symbol map, line symbol map, and choropleth map. They present geographic phenomena with the use of points, lines, and areas, respectively. Besides, these techniques are frequently used in animated cartography [49]. To strengthen the visual cue, we used cartographic redundancy in the form of simultaneous change of size and color on the map. The dynamic parameters of the maps were the same, in order to ensure their comparability. Figure 1 shows six animated maps that were used to conduct the study. The next sections feature their detailed descriptions.

3.1. Enumeration Units and Temporal States

The criticism regarding oversimplification of the animated map used in the studies motivated us to adopt a greater number of enumeration units as it is in [4,19,50]. Animated maps often present the change affecting the phenomenon in a few, or even a dozen, time intervals. That was why we took into consideration also a greater number of temporal states, which had not previously been done by other researchers. We decided that such a solution would be more in accordance with the actual purpose of animated mapping.

The proportional symbol map had 11 enumeration units and 11 temporal states. The map featured points representing places in Japan with the maximum rainfall in a given year. The line symbol map had 20 enumeration units, which were river fragments, and 12 temporal states. The map represented the watershed of the river San. The choropleth map, finally, had 8 enumeration units and 10 temporal states, and presented unemployment rate in Saudi Arabia. In order to prevent a situation whereby the user's knowledge about the phenomenon would influence the results, fictional data was used. This decision was motivated by the fact that the subject's knowledge about a given phenomenon influences the results of the experiment. The participant, instead of answering the questions on the basis of data obtained from the map, might complete the task without the need to analyze the animations [51].

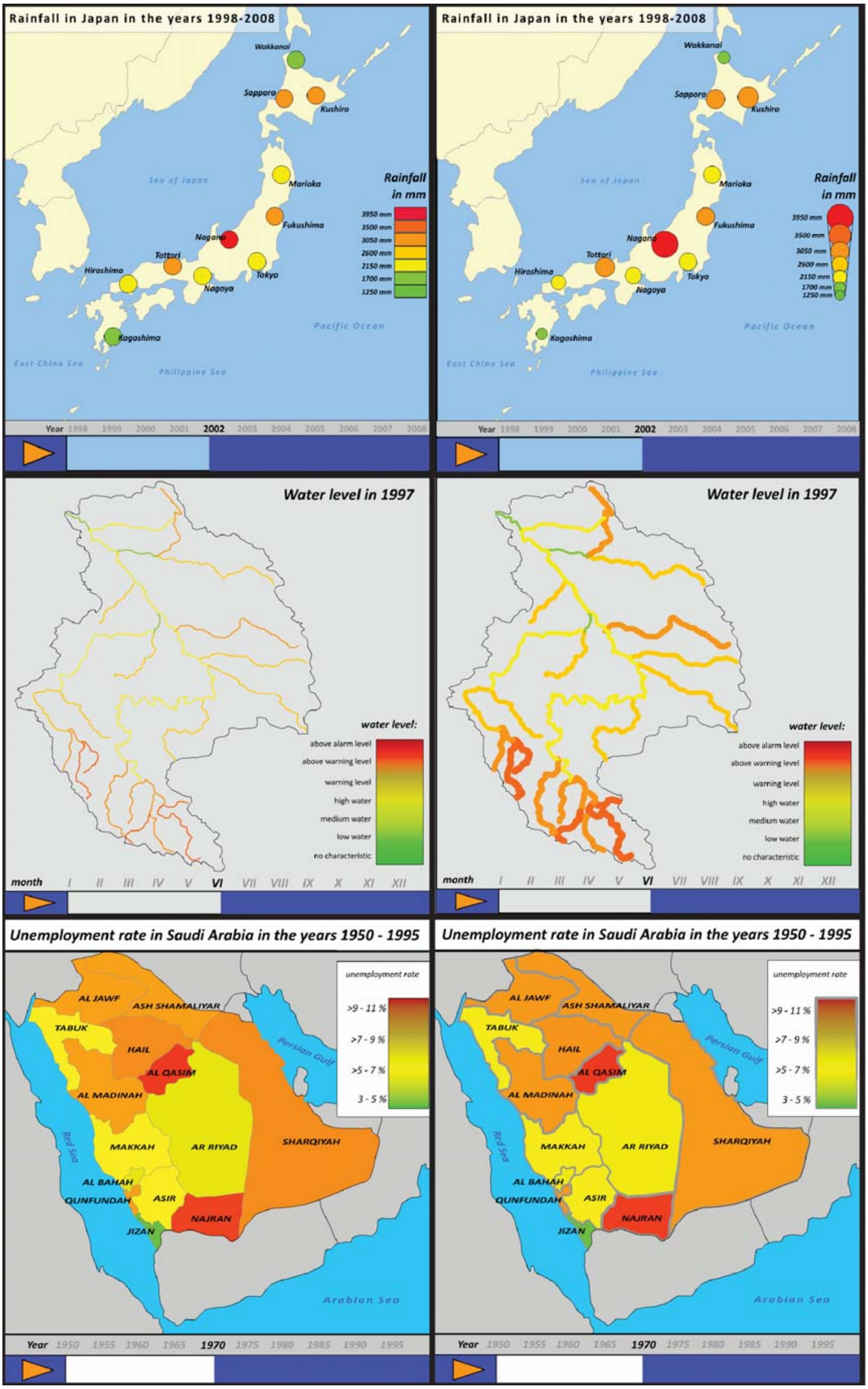

Figure 1. Six animated maps which were used in the research. Variants on the right feature cartographic redundancy.

3.2. Visual Variables and Cartographic Redundancy

The chosen cartographic techniques make use of two visual variables acting as visual stimuli. Through color or size, the user recognizes the intensity of the phenomenon, and thanks to the modifications affecting those parameters, he/she is able to recognize its intensity in the consecutive year. This enables him/her to notice whether the value of the phenomenon is greater or smaller than previously. On the basis of the whole animation and the comparison of the particular states, the user can deduce when and where the phenomenon's intensity was at its highest and when at its lowest. The comparison can only be accurate on condition that the visual stimuli in the form of visual variables enable the user to perceive the changes.

The techniques chosen for this study are based on three geometric types: points, lines, and areas. Each of them served to create a map where color was the main visual stimulus illustrating changes in phenomenon intensity. Previous studies had made use of greyscale color scale [4,19,50]. In our study, we used a color scale from green to red. It was an associative color scale, where green had positive, and red—cautionary associations [52]. Using this color scale is risky where people with color vision deficiencies (CVD) are concerned. However, as borne out by research, this concerns only 4% of the population [53]. A research question thus arises: is an associative color scale conducive to noticing maximum and minimum values on an animated map?

A redundant manipulation of the size variable was aimed at improving the perceptibility of maximum and minimum values of phenomenon intensity on the map. Redundancy has been used in cartographic research before, especially for generation of route directions [54,55]. In order to test the effect of redundancy on the perception of changes on the animated map, we designed three additional maps. The total of six maps can be seen in Figure 1. For the map employing point symbols, redundancy was achieved through manipulating point size, which yielded a proportional symbol map. In the case of the line symbol map, redundancy consisted of changing line width. On the choropleth map, finally, it was achieved by manipulating border width of administrative units.

3.3. Smooth vs. Abrupt Transition

The insufficient knowledge of how the type of transitions used on the map may influence the user's detection of the occurring changes has led us to address this problem in the study in hand. For the point symbol map, we decided to use abrupt transitions, and for the others—smooth transitions. In so doing, we wanted to find out if the choice of transition type would affect the perceptibility of maximum and minimum values on maps with cartographic redundancy. For the maps featuring redundancy, the smooth transition was applied not only to color, but also to size. Conducted studies confirm that the use of color and size to highlight information in visualizations is justified [56,57]. The method proposed by the authors might be understood as redundancy, but also as magnification, due to the use of the most popular visual variables [58]. For the proportional symbol map, where we used an abrupt transition, seven classes were defined, in accordance with the commonly known cartographic principle stating that the number of classes should not exceed seven, give or take two [47].

3.4. Dynamic Variables on Animated Maps

The proper setting of dynamic parameters is a crucial element of cartographic animation design. Based on previous studies [59,60], we decided that a single frame would be displayed for a duration of 3 s. Such a duration ensures a sufficient effectiveness of the animated map in conveying spatial information. The duration of a single frame was the same also for the maps with cartographic redundancy. Thanks to this, the total duration of every animation was about 30 s. We did not opt for a longer display of a single frame due to the great number of temporal states. We also decided that on every map, the order of display would be chronological, even though [13] suggested changing this parameter with a view to highlighting the most interesting moments of the animation. We did not analyze the significance of the magnitude of change, which had already been a focus of the study by [19].

For the animated map featuring particular years understood as temporal states, we added a timeline. Every year corresponded to a different intensity of the phenomenon. It is a common way of presenting the display time variable [61,62]. Thanks to the timeline, the study on user perception could be extended to cover not only whether the user noticed the particular value of the phenomenon, but also whether he/she could state when this value appeared. We wanted to find out if change blindness applies to an equal extent to the content of the map itself and to the content of the timeline, as this had not been adequately studied before.

4. User Testing

4.1. User Characterictics

In order to test the influence of cartographic redundancy on the reduction of change blindness in the users of animated maps, the authors used methods borrowed from psychology, including the maps being tested offline by the user. The respondents were students of [the name of the institution], a total of 60 people—28 men and 32 women. The average age was approximately 21 years. The participants had secondary education and were students of various non-geographic departments. The authors aimed at public users with Internet access, aged 18–24, since other similar studies had focused on such subjects [4,63]. Asked about their frequency of Internet use, they all claimed to use it on an everyday basis. The reason for posing this question was that spatio-temporal maps are mostly available on the Internet. As it turns out, experience in reading animated maps is an important factor [64]; that was why the participants were asked how much experience they had with animated maps and where they usually encountered them. Most of the subjects (85%) admitted to rarely using such maps; others (15%) to hardly ever using them or not using them at all. Those who did, usually encountered them on the Internet (80%), or, less frequently, on television (20%). Thus, the chosen group of respondents did not have much experience with using animated maps.

The users were divided into two groups, each consisting of 30 people. The first group was shown three animated maps where only color variable was used to present the phenomenon. The second group viewed the same three maps, but with an additional visual variable—size.

The research sample was chosen at random out of a population aged 18–24 with secondary education. The random selection made it possible to include people with no previous experience with animated maps as well as people who did have such experience. Results show that most of the participants had little experience with animated map use. This is important, as a sample involving too many people with a lot of experience of using animated maps would not be representative of a public Internet user. The population targeted in this study can be described as one of the most active group of Internet users; hence, they might be defined as the public Internet user. Targeting people who do not use the Internet on a daily basis could lead to false conclusions. On the other hand, focusing on people with ample experience in using animated maps means dealing with an expert trial. Hence, those two factors—frequency of Internet use and experience with animated maps, mean that the research group chosen by us is a representative one and can be compared to similar cartographic studies conducted by other scholars in the field.

4.2. The Course of the Experiment

Every user was asked to diligently complete the experimental task. The experiment began with an introductory task featuring an animated map and some personal questions. Then, the users were shown the first animated map, the one employing point symbols. The first group analyzed maps without cartographic redundancy, the second group—the maps with redundancy. The time from launching the animation till providing all the responses was measured. After viewing the whole animation, every user could replay it any number of times. After the point symbol map, the user was shown the line symbol map and finally, the choropleth map. In most cases, the replay option was used only once. After the viewing, every user was asked whether the maximum and the minimum value of the phenomenon had appeared on the map. If the user answered in the affirmative, he/she was asked to indicate the spot on the map and the year on the timeline. In the case of the line symbol map, the subjects were asked, beside pointing out the maximum, to identify also the location on the map and the point on the timeline when the water reached the "above warning" level. For the choropleth map, more than one correct answer could be ticked. Every user stated correctly that the maximum and the minimum had appeared, but not every one of them was able to correctly point out their location on the map/timeline.

5. Results

5.1. Reduction of Change Blindness

Figure 2 features charts illustrating the frequency of noticing extreme values on the map and on the timeline, as obtained from a two-way ANOVA analysis. The vertical axis presents the level of correct detections on the map and on the timeline. The horizontal axis features the basic geometric symbol in the given animation. In order to evaluate the influence of cartographic redundancy on the perception of maximum and minimum values on particular maps, we used the chi-squared test; to analyze the response times—the Mann-Whitney U test.

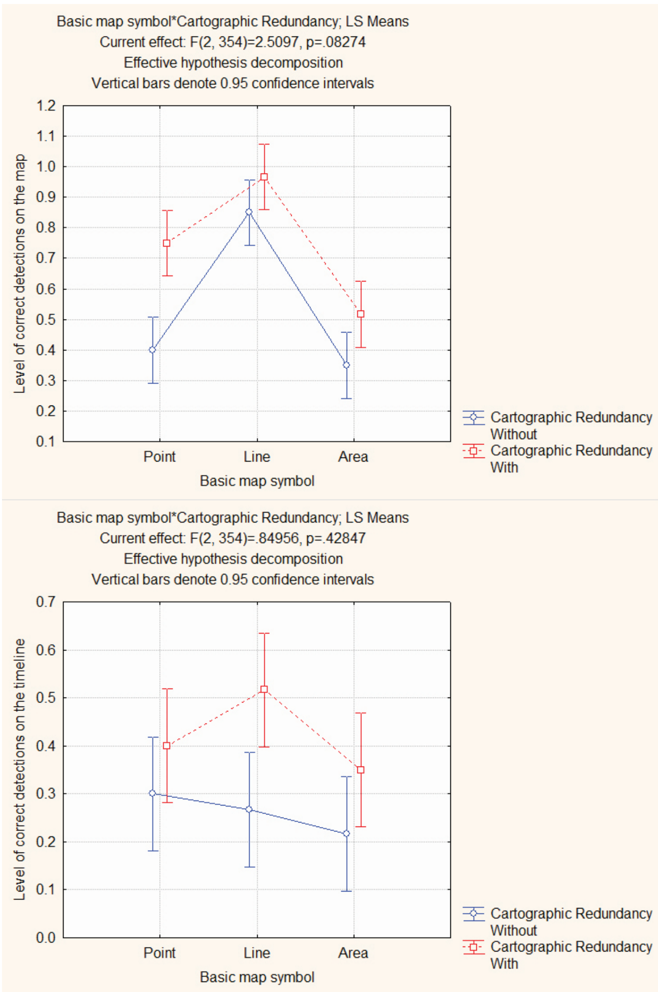

Figure 2. Level of correct detection on the map and on the timeline according to three basic map symbols.

When it comes to the users identifying the places on the point symbol map where the maximums and minimums occurred, cartographic redundancy improved their performance by about 35 percentage points (χ^2 = 0.0001). As for noticing the moments on the timeline when those extreme values were recorded, the influence of cartographic redundancy is inconclusive for the whole task. A slight improvement (10 percentage points) was recorded, but this result was not statistically significant (χ^2 = 0.25).

Tasks involving line symbol map turned out to be the easiest for the participants, which translated into the number of correct responses in the case of the map without cartographic redundancy. It can be noticed that the simultaneous modification of two visual variables brought about an improvement in identifying locations on the map by 12 percentage points (χ^2 = 0.026) and in pointing out moments of their appearance on the timeline by 23 percentage points (χ^2 = 0.005). Across the entire task, participants did worse when asked to identify the "alarm level" both on the map (13 percentage points; χ^2 = 0.128) and on the timeline (20 percentage points; χ^2 = 0.121).

It should be noted that when it comes to identifying the maximum and minimum values on the choropleth map, cartographic redundancy did not bring about the expected effect (χ^2 = 0.194; χ^2 = 0.165). If one considers the task on the whole, however, it transpires that redundant highlighting improves the perception of extreme values on the map by 17 percentage points (χ^2 = 0.065). As far as finding those values on the timeline is concerned, modifying two visual variables does not result in a significant improvement of user's perception. In the context of the task as a whole, there was an improvement by 13 percentage points (χ^2 = 0.105).

Taking into account all the results, the authors conclude that cartographic redundancy, understood as a simultaneous modification of color and size, has a positive effect on reducing change blindness in map users identifying the location of extreme values on the map. On the point symbol map, the improvement in perception throughout the entire task amounted to 35 percentage points (χ^2 = 0.0001). On the line symbol map, the recorded improvement was 12 percentage points (χ^2 = 0.026). On the choropleth map, 17 percentage points (χ^2 = 0.065). On the other hand, when it comes to identifying the extremes on the timeline, it must be noted that the application of redundancy had an insignificant influence on the participants' performance throughout all three tasks. It was only in the case of the line symbol map that redundant highlighting brought about a statistically significant, 23-percentage-points improvement in the perception of maximums and minimums on the timeline (χ^2 = 0.005).

5.2. Response Time

The time that the respondents took to answer the experimental questions varied depending on the task. Without the aid of cartographic redundancy, the map for which the participants needed the most time was the point symbol map. Here, the subjects needed an average of 154.2 s to provide their answers. The least time was needed in the case of the line symbol map—108.5 s on average. This task turned out to be the easiest one as well. To answer the questions regarding the choropleth map, the participants took 130.3 s on average. The application of cartographic redundancy affected the response times. The average response time for the point symbol map decreased to 127.8 s (p = 0.0024). For the line symbol map, reaction time decreased to 97.8 s (p = 0.1392). For the choropleth, which proved the most difficult one in terms of identifying extreme values, the participants needed on average 160.9 s to provide their answers (p = 0.0345).

6. Discussion

Existing psychological studies have borne out that the human perception is limited and that for this reason, we are not able to notice changes occurring in more than five places simultaneously [42,65]. It must be noted, moreover, that in the case of animated maps, the simultaneous changes might be of varying kinds. Beside the appearance/disappearance of objects, there might occur an increase/decrease in the intensity of the presented phenomenon, which is reflected as a change affecting a visual variable. The particular increases/decreases occur in various years, which is an additional complication in the map reading process. Besides, the phenomenon might reach its maximum or minimum value. As borne out by [19], there are three levels of noticing changes on the animated map. At the first level, the user only notices the change taking place, but is unable to describe it in any further detail. At the second level, he/she is capable of stating whether the change was an increase or a decrease. At the highest level, the user not only detects an increase/decrease, but also comprehends its value. We propose to extend this framework by two additional elements: first, stating whether the intensity noted at a given spot is a maximum or a minimum value; second, pointing out on the timeline the moment when the change occurred—in other words, perceiving not only the place, but also the time of the change.

According to Miller's principle [47], the optimal number of classes on the map is seven. However, in the case of classed choropleth animated maps, it is advisable to limit the number of classes even more [30]. However, in the case of unclassed choropleth maps, a proper design of the animation (e.g., smooth transitions) might make it possible to avoid the loss of spatial information and prevent the user from getting the "jumpy animation" impression while maintaining the higher number of classes [66]. It should also be noted that the interpretational difficulties connected with animated maps might also stem from the great number of temporal states. No studies to date have yielded any conclusions regarding the optimum number of temporal states. However, on the basis of the conducted research, we are inclined to believe that animated maps have a general and limited purpose. Given that the total duration of an animation should fall between 30 s and 60 s [33] (p. 181), and the effective display duration of a single state is 3–5 s [60], we proposed that the number of temporal states should not exceed 10. It is also believed that the higher the degree of changes on the map, the higher the risk of change blindness affecting its users [50].

The effectiveness of animated maps depends also on the user's attention, which is affected by the graphical representation of the scene. The more recognizable it is, the easier it is for the user to analyze the animated map and the changes occurring there [67]. Some graphical solutions might cause perceptual distortions. Examples of such negative influence on user's perception include geometrical-optical illusions, such as the Hering illusion, the Zoellner illusion, or the Ebbinghaus illusion [6,68] (p. 309). As pointed out by [9], in the process of map design one needs to take into consideration the Gestalt theory and the principles of grouping, similarity, simplicity, and common fate.

Various visual variables have varying potential for reducing change blindness. The size variable is considered the most useful in this respect [21]; however, not all cartographic presentation techniques employ this variable, so using it is not always a possibility. Some techniques, such as the choropleth map, are based solely on color. It must be noted, though, that various color scales are used depending on what phenomenon is being presented. Besides, a change of color is very difficult to notice compared to other variables [69,70]. That is why for the cartographic techniques using color as the main visual stimulus, we propose strengthening the cue through cartographic redundancy. An interesting finding in this paper is that participants are significantly better with the animated graduated circles (i.e., size changes) compared to the choropleths (i.e., color value changes). The biggest differences in the correctness of answers were for those symbols that had the largest differences in size—the points—while the weakest differences were for the symbols with the smallest size differences—the polygon boundaries. Because larger changes are easier to notice than smaller changes. Also, the color in the point symbols is classed and each color hue is quite clearly differentiable from the next. This may be less likely in the continuous color ramps. This is backed by previous studies on the significance of size as a variable attracting the user's attention [21,71,72]. Even though we focused only on one case of using size as a redundant variable, there are more ways of highlighting changes via redundancy [73]. In the case of choropleth maps, apart from the option of increasing border width, cartographic redundancy might also be achieved through enlarging the administrative units. The resulting map would then be a cartogram. Note that there are other possibilities of coding data. Besides, many researchers base their experiments on only one visual method of coding data and on one mapping method [46,74]. The choice of different colors may impact conclusions [75,76]. The authors agree that the various methods of cartographic redundancy and their combinations with various mapping techniques should be tested by further studies.

As proposed by [28], smooth transition might be used in order to highlight the changes occurring on the animated map. This is applicable not only to the choropleth maps, but also to other mapping methods featuring size as the main visual stimulus.

The proposed method of redundant encoding meets the requirements of the FIVE framework, which concerns the issue of emphasizing spatio-temporal data [58]. According to this framework, cartographic redundancy is a prominent method of visualization and could be considered one of the most effective ones. The innovative usage of visual variables—color and size for the purpose of highlighting spatial information can successfully be used to reduce change blindness on animated maps. Research shows that a simultaneous modification of these variables significantly contributes to improving the user's perception of extreme values on the map. In the case of the point symbol method, the line symbol method, as well as the choropleth map, applying this kind of cartographic redundancy contributes to an improved effectiveness. Studies have shown that cartographic redundancy does not completely solve the problem of change blindness, but it may minimize it. The question that still remains regards the perception of the given phenomenon's appearance on the timeline [2]. The improvement in perception is in this case insignificant and the question of how to reduce change blindness in this context still remains open. So does the more general issue of the human processing of spatio-temporal information at large.

7. Summary

Thanks to animated mapping, many geographic processes can be illustrated in a dynamic fashion. In the above paper, we analyzed only some of the problems connected with both map design and the limits of human perception. Animated maps present the changing intensity of a phenomenon by manipulating graphical parameters such as color or size. In order to find a maximum/minimum value, the user has to notice it among other changing elements; then, he/she must interpret it in accordance with the legend, and finally, remember its location and the moment on the timeline at which it occurred. This might be problematic due to the number of changing symbols on the map, but also to the number of temporal states.

The design of the animated map might also facilitate or hinder the user's perception of the extreme values and their location in time and space. Mapping methods which facilitate perception are the ones that employ size as the basic variable presenting phenomenon intensity. The use of size as tested by us is only one of the possible ways of enriching the visual stimuli on the map; hence, it is necessary to keep searching for visual methods that will help reduce change blindness in animated cartography.

The conducted study has certain limitations. Using color as the main visual stimulus is not an appropriate choice for all cartographic techniques; hence, it would be better to use size as the main visual stimulus and compare the obtained results. Interesting conclusions could also be drawn from comparing the effect of cartographic redundancy on maps with smooth vs. abrupt transitions.

It seems that certain issues connected with the effectiveness of animated maps are worth considering. Most of all, the following question begs an answer: is it possible to use combinations of different visual variables for the purpose of reducing change blindness on animated maps? The two variables used in the study, i.e., color and size, are applicable only to the mapping methods based on them. What about the statistical surface map? How could visual variables be used to enrich techniques based on other variables? Other questions that should be asked in the context of animated map perception, are: How to increase the perceptibility of changes on the timeline? Why is the perception of the timeline more difficult than the perception of the map itself? The number of temporal states on animated maps is an issue that has not been sufficiently studied; hence, not much is known in this regard. It would be advisable to think of ways to improve the perception of the timeline in animated cartographic presentations. Could interactive tools be a solution? Are there any ways to visually enhance the timeline in order to aid its perception?

We believe that addressing the above issues might improve the understanding of animated maps. Cartographic animations have an immense potential for presenting changes in time and space; however, more thought must be given to their advantages and disadvantages. This search should be geared towards accommodating user needs and focusing on visual perception.

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