RELATIONSHIPS BETWEEN THE DISTORTIONS IN MAP PROJECTIONS AND THE USABILITY OF SMALL-SCALE MAPS

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Abstract
User-studies in cartography are becoming popular research topics recently. However, only a small number of studies measure the effect of distortions caused by map projections. Via an online questionnaire (247 participants), this research investigates how the different kinds of distortions influence the understanding of the map. Furthermore, we explored map usage patterns of different demographic groups. With this information, projections may be classified as appropriate or not favourable regarding a specific group. The results show strong preconceptions among older (30+) map users, especially among those who studied geography. Younger participants, however, could benefit from low-distortion maps. We also showed that pole-lines are misinterpreted in all groups. Many of our participants even believed that the northern and southern pole-lines are connected like the eastern and the western edges of the map. Our results can help cartographers to choose the proper projection for their audience.

INTRODUCTION

The cognitive map of our local area in our mind is formed by first-hand experiences. In the case of larger areas where direct cognition is not an option, people can only expand their knowledge by reading small-scale maps. A problem with small-scale maps lies within the difficulty of verifying their content with direct experiences. Thus, what map readers see on a map will be accepted as truth. In addition, visual stimuli, graphic designs, and maps tend to have a substantial impact on people's view of the world. This was often used by political propaganda, even in cartography (Jeney, 2015). An important aspect of maps is that they are only a model of the "geographic reality". For instance, it is impossible to represent the curved surface of the Earth on a flat paper without distortions. On small-scale maps, these distortions cause visible differences between the map and the globe. Also, the distortions may cause false impressions of the geographic relations to the map readers (Battersby & Montello, 2009).

One of the reasons for the diversity of existing projections is that each shows different properties of spherical objects less distorted and distorts others more. After the rise of digital cartography and GIS, maps could be reprojected with only a few clicks using the proper software. Thus, creating user-friendly and effective projections is a great possibility for cartographers, which we wish to promote with this paper.

Numerous studies examined the map reading skills of map users, and factors that affect these skills (e.g. Gilhooly et al. 1988; Guzmán et al. 2008; Ito & Sano 2011; Ooms et al. 2012; Albert et al. 2016), although they only tested large-scale maps. Wakabayashi (2013) showed that reading small and large-scale maps require different competencies. While the latter one needs spatial-cognitive skills of orientation and map reading, the prior one mainly requires geographic knowledge.

Nevertheless, there are a few studies that aim to find the connection between map users and map projections. The motivation for this study came from Šavrič et al. (2015), who wanted to choose the projection of a world map based on the opinions of map readers. Their user study did not include any map reading tasks, so their study was based more on aesthetic opinions. It is also important to add that most of their test subjects were from the USA and India. We imply that this was a reason why the Robinson projection, which often appears in American cartography, reached a higher score than the Winkel III, which is mainly used in Europe. This assumption is based on a study of the Research Group on Experimental Cartography at Eötvös Loránd University, Hungary, which found that cultural background can affect map reading (Albert et al. 2016). The study of Šavrič et al. does not mention that if a projection is popular among the map readers, will it also help map reading? This means finding which distortion parameters have the most effect on map reading is still an open question. Of course, there are studies that examine the effects of certain distortions (e.g. Anderson & Leinhardt, 2002; Battersby & Montello, 2009; Hruby et al. 2016), but these usually work with a small number of test subjects, who are mainly geography students at universities.

The goal of the present study was to test the effects of different distortions on map reading with a large number of test subjects. We wanted to distinguish which demographic variables (age, qualification, and map usage frequency) influence the correct interpretation of distortions in map projections to define which distortion parameters are the best choices for different users. To do so, we conducted a user study with an online test that included seven questions on various map reading tasks. Each question had 6 answers and an "I don't know" option. During these tasks, the participants had to face various types of map distortions: areal distortion, meridian convergence, antimeridian cuts, discontinuities, curved graticule lines, pole-lines and the curvature of mapped geodesics. We created 2 maps for each question: one with an unfavourable projection for a test group, and another with an optimal projection for a control group. The questions and the answers were the same for both groups, only the maps were different. Each question had its own projection-pairs that were chosen for the certain task. In this way, we could look for distortions that had significant differences between the control and the test group. This would prove to us that an inappropriate projection can cause false implications during map reading.

THE USER-STUDY

Data collection

We created an online questionnaire to test the effects of various projections on map reading. The website was available in Hungarian and English, but due to the low number of English participants, we only evaluated the Hungarian data. The first few questions collected the demographic statistics of participants, such as gender, age, the field of study/qualification, map reading habits. We asked them about the type of maps they use most often (world atlases, globes, thematic atlases, digital globes, online map services) and the frequency of map use (every few days, once a week, once a month, every few months, less than every few months). The participants were then separated into two groups: a test group and a control group. The grouping of the test subjects was supervised with an algorithm so that the ratio of different demographics would be near the same in the two groups. The participants were also asked in advance to use only the maps displayed on the screen.

The test was online from 23 January 2017 to 13 April 2017. During this time, the test had 322 participants in total. After filtering data, there were 247 completed tests sufficient for evaluation. The average fill time of the test was five and a half minutes. Along with the unfinished tests, we also filtered the ones with fill time below 2 minutes 21 seconds, and above 14 minutes 29 seconds. These limits were defined by the natural breaks found in the dataset.

The Participants

The participants can be classified by various demographic statistics (Figure 1). These were: gender (male, female), age (below 20 years, 21–25 years, 26–30 years, above 30 years), education (primary, secondary, and higher), qualification in the fields of geography or earth sciences, and map usage habits.

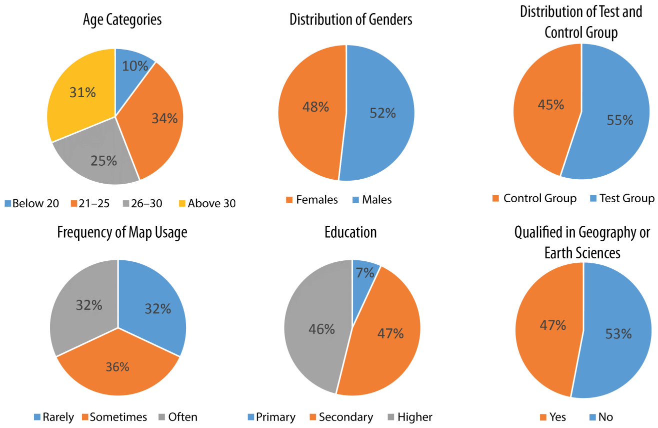


Figure 1. The demographic characteristics of the participants.

The distribution of genders was roughly equal: 128 male and 119 female participants. A total of 111 test subjects had qualifications of higher education, 116 had secondary education, but only 17 participants had primary education (recruiting test subjects with primary education is a recurring problem). There were 116 participants who were qualified in the fields of geography or earth sciences, and 131 who were qualified in other fields. These data were required to know how the different kinds of distortion affected the professionals. Finally, the results showed that 79 participants often use maps, 89 test subjects sometimes use maps and 79 participants rarely use maps. The distribution of participants between the test group and control group was almost equal: 136 participants were assigned for the test group, and 111 for the control group.

Statistical Processing

The results were analysed using two methods. First, the proportion of correct responses was compared for different groups. It had to be found out how much the variation was due to the uncertainty of sampling and how much was due to the choice of projection. Since the answer was either correct or incorrect, this shows a discrete distribution; but due to the large number of samples and the central limit theorem, the distribution of correct answers can be considered normal with a good approximation. In this case, the two-tailed t-test is applicable, which gives an estimate of the likelihood that the uncertainty of sampling resulted in the different rates of correct answers. If this probability was lower than 5%, the results are highlighted (Table 1) and are referred to as *significant according to the t-test*.

Results may be refined further by saying that incorrect answers are not equally bad. This was accomplished by ranking all possibilities of answers between 1 (worst) and 6 (best). (See figure captions.) Then, the two-tailed Mann–Whitney test – hereafter U-test –, which is appropriate for ordinal scales, was used to estimate the probability of a better answer from the control group while selecting one random subject from the test and one from the control group, i.e. the better map resulted in better response. During processing, the correction of tied ranks – i.e. identical given answers – and the continuity correction were taken into account (Bergmann, Ludbrook & Spooren, 2000). On this basis, if the probability that the choice of projection did not affect the response was below 5%, the results were identified as *significant according to the U-test*. (Table 2)

Table 1. The proportion of correct answers per demographic groups. Highlighted results are significantly better according to the t-test at significance level 95% (Szigeti & Kerkovits, 2018).

	Gender				**Education**						**In geosciences**			
	Men		*Women*		*Primary*		*Secondary*		*Higher*		*Not qualified*		*Qualified*	
	Test	Contr.	Test	Contr.	Test	Contr.	Test	Contr.	Test	Contr.	Test	Contr.	Test	Contr.
Areal distortion	30.6%	32.1%	26.6%	30.9%	10.0%	28.6%	25.8%	24.1%	34.4%	40.0%	22.5%	30.0%	35.4%	33.3%
Meridian conv.	83.3%	67.9%	82.8%	72.7%	70.0%	71.4%	79.0%	68.5%	89.1%	72.0%	81.7%	66.7%	84.6%	74.5%
Antimeridian	56.9%	66.1%	50.0%	56.4%	50.0%	57.1%	56.5%	59.3%	51.6%	64.0%	53.5%	63.3%	53.3%	58.5%
Discontinuities	34.7%	51.8%	43.8%	52.7%	50.0%	57.1%	38.7%	57.4%	37.5%	46.0%	40.8%	53.3%	36.9%	51.0%
Graticule	95.8%	91.1%	95.3%	94.5%	80.0%	100%	95.2%	92.6%	98.4%	92.0%	94.4%	91.7%	96.9%	94.1%
Pole-lines	43.1%	76.8%	20.3%	76.4%	10.0%	100%	29.0%	74.1%	39.1%	76.0%	28.2%	80.0%	36.9%	72.5%
2nd term of corr.	47.2%	37.5%	37.5%	41.8%	10.0%	42.8%	38.7%	37.0%	51.6%	42.0%	35.2%	40.0%	50.7%	39.2%

	Age								**Map reading**					
	Under 20		*21–25*		*26–30*		*Above 30*		*Rarely*		*Sometimes*		*Often*	
	Test	Contr.	Test	Contr.	Test	Contr.	Test	Contr.	Test	Contr.	Test	Contr.	Test	Contr.
Areal distortion	22.5%	30.0%	35.4%	33.3%	11.9%	27.0%	38.0%	28.2%	11.9%	27.0%	38.0%	28.2%	34.1%	40.0%
Meridian conv.	81.7%	66.7%	84.6%	74.5%	83.3%	73.0%	80.0%	66.7%	83.3%	73.0%	80.0%	66.7%	86.4%	71.4%
Antimeridian	53.5%	63.3%	53.3%	58.5%	52.4%	59.5%	52.0%	64.1%	52.4%	59.5%	52.0%	64.1%	56.8%	60.0%
Discontinuities	40.8%	53.3%	36.9%	51.0%	31.0%	51.4%	44.0%	48.7%	31.0%	51.4%	44.0%	48.7%	40.9%	57.1%
Graticule	94.4%	91.7%	96.9%	94.1%	95.2%	89.2%	96.0%	92.3%	95.2%	89.2%	96.0%	92.3%	95.5%	97.1%
Pole-lines	28.2%	80.0%	36.9%	72.5%	31.0%	86.5%	38.0%	66.7%	31.0%	86.5%	38.0%	66.7%	27.3%	77.1%
2nd term of corr.	35.2%	40.0%	50.7%	39.2%	33.3%	37.8%	52.0%	43.6%	33.3%	37.8%	52.0%	43.6%	40.9%	37.4%

Table 2. The results of the U-test. Sign + marks that a projection with more favourable distortion helped, sign – indicates that it resulted in worse answers at significance level 95%.

	Gender		**Education**			**In geosciences**		**Age**				**Map reading**		
	Men	*Women*	*Primary*	*Secondary*	*Higher*	*Not qualified*	*Qualified*	*Under 20*	*21–25*	*26–30*	*Above 30*	*Rarely*	*Sometimes*	*Often*
Areal distortion			+			+						+		
Meridian conv.					–	–								
Antimeridian														
Discontinuities	+													
Graticule														
Pole-lines	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2nd term of corr.	–		+				–	+						

RESULTS FOR EACH TASK

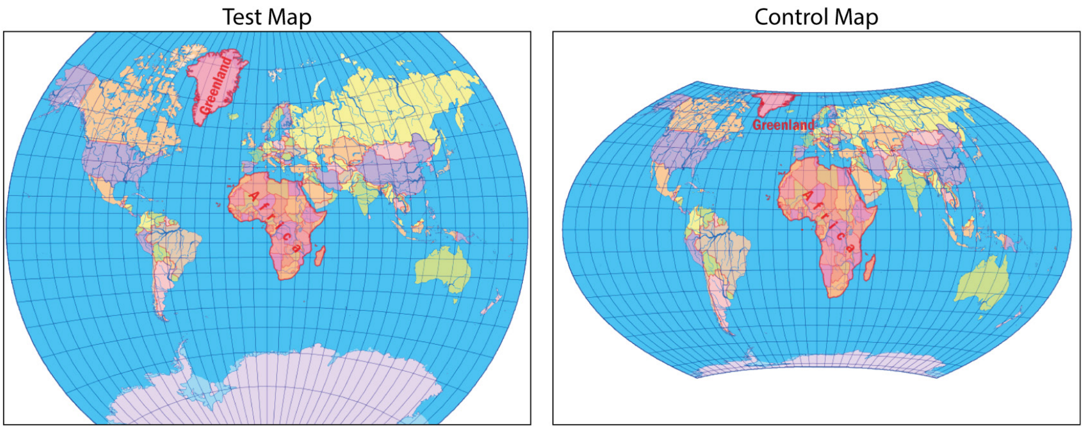
Areal Distortion

Research by Battersby and Montello (2009) has shown that map readers are aware of areal distortions on the map, and in their survey, test subjects even overcompensated the distortion. Since only students of geography participated in this study, we considered checking results for a wider audience. As in the aforementioned research, we did not ask the participants to read the area in square kilometres, but to compare it to a reference area (Greenland) as a unit. They had to answer how many times the area of Africa is bigger than Greenland. The two areas are located at different latitudes, so the projections may show significant differences in their size.

For the test group, Battersby chose the Mercator projection, because it is very popular in American cartographic practice. As Hungarian cartographers do not use this projection for world maps at all, we used the similarly unfavourable Van der Grinten I projection, which is more common in Hungarian world atlases The task of the control group was carried out on an equal-area map. We did not want the excessive angular distortions of the projection to confuse the readers, so they worked on a Wagner-transformed Hammer map, a more favourable basis for world maps (Figure 2).

28.7% of respondents answered correctly that Africa is fifteen times larger than Greenland. The most common incorrect answer was “five times larger” with 26.5%. In contrast, 31.5% of the control group indicated the correct response, but 33.3% indicated the incorrect five times bigger size.

Therefore, many of the participants underestimated the area of Africa, even in the equal-area projection; they assumed the difference between the two areas to be smaller. Significant differences were only found using the U-test among subjects with primary education, rare map users, and participants without qualification in earth sciences. These groups were likely to take the distortion of the projection less into consideration, with the vast majority of respondents choosing the “one-and-a-half times bigger”, which the test map directly suggests, or the slightly compensated “three times larger” answers.



In reality, how many times is the area of Africa larger than the area of Greenland?
A) Both have the same size (1) B) 1.5 times larger (2) C) 3 times larger (3)
D) 5 times larger (4) **E) 15 times larger** (6) F) 25 times larger (5)

Figure 2. Test question of the areal distortion. The correct answer is shown in bold, 1 is the worst, 6 is the best answer.

Meridian Convergence

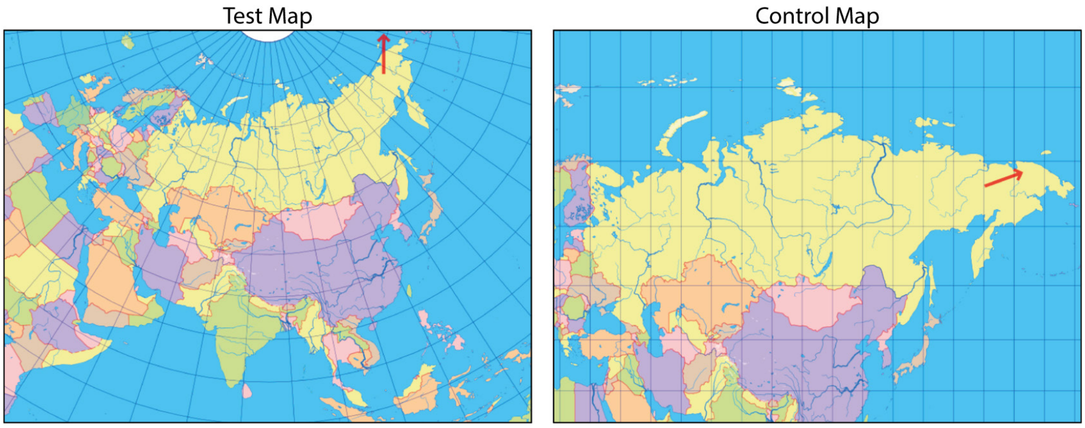
On the map, the directions can theoretically be read off in the following way: the top of the map is conventionally facing north, and the map user can estimate the azimuth of any line based on the angle enclosed by the vertical axis of the map. In practice, three properties of the projection affect this: the *meridian convergence* – north is not exactly upwards at certain points of the map; the *first term of correction* – the mapped angles generally do not correspond to their terrestrial counterpart; and the *second term of correction* – geodesics usually appear as curved lines on the map. The correct reading of the directions was examined separately for short and large distances, the latter being explained in the last question. In this task, ignoring meridian convergence will cause a 60° error, which is significant when reading small-scale maps.

Russia, which lies along a parallel, is usually mapped in a conic projection, the distortions of which can be said to be favourable. However, due to the high latitudes and the large differences in longitude, the images of the meridians heavily converge, and the Chukchi Peninsula bends up at the edge of the map. In such projections, the arrow pointing up in Chukotka is no longer pointing to north but rather to east-northeast. Thence, our test participants worked on a De l'Isle conic projection, and the first term of correction (3°) was neglected (Figure 3).

In the normal aspect of cylindrical projections, there is no meridian convergence. Forcing the additional constraint of conformity results in the Mercator projection. This projection is not applicable for such high latitudes. Thus, the cylindrical stereographic projection of Gall was chosen for the control group. Its distortions are less disturbing and the first term of correction (7°) is again negligible (Figure 3). The arrow, in this case, did not point upwards.

83% of the test group correctly thought that the arrow is pointing to the east-northeast. Roughly equal number of participants marked each of the remaining answers. Conversely, 70.3% of the control group indicated the correct response and 13.5% of the group members incorrectly answered north. The t-test and the U-test show essentially the same pattern. For each group, users of test maps with a familiar projection have achieved better results than those using unusual looking control maps. The U-test value approached the critical value in most groups, but it was only exceeded among people with higher education and without qualification in geosciences.

The favourable projection hindered rather than helped to understand the map. The results show that meridian convergence does not confuse reading off the directions, as the map readers rely on the graticule lines. At the same time, the unusual representation of the projection used for the control map may have disturbed map reading.



In which direction is the red arrow pointing in Chukotka?

A) North (4) B) South-southwest (1) C) East (5)
D) Northwest (3) E) South (2) **F) East-northeast** (6)

Figure 3. Test question of the meridian convergence.

Cut on the Antimeridian

Most projections display the antimeridian twice on the plane so that the images of this line give the eastern and western contours of the map. For this reason, close points near the antimeridian show up at the opposite parts of the map, spoiling the visualization of global relationships.

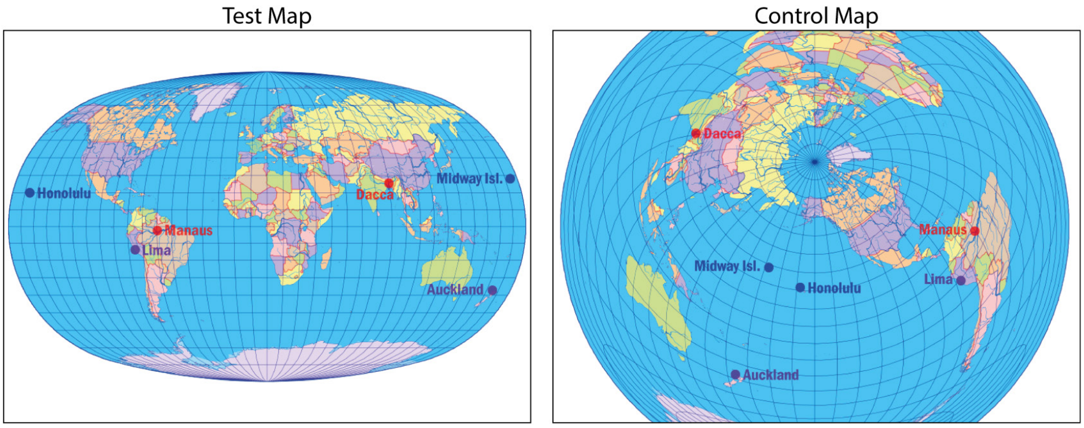
In a recent paper (Gott, Mugnolo & Colley, 2007), a projection showing distances with the least possible distortion was developed. The researchers, though not aware of it, practically obtained a projection from the projection set of Ginzburg, which has long been known to have an optimal distortion (Tolstova, 1969). Gott connected point pairs near the antimeridian with straight lines during computation, implicitly assuming that the map reader does not estimate the distance in two sections crossing the edge of the map. However, this hypothesis is lacking any evidence.

Effects of antimeridian were only investigated later using actual experiments (Hruby, Avelino & Ayala, 2016). In this case, research was also done exclusively with geography students. Therefore, it is advisable to extend it to a wider audience. In contrast to the assumption of Gott, the test subjects connected the point pairs in the right direction; the average distance estimation error did not exceed 2%, which could be attributed to the effect of the strongly distorting Plate Carrée projection. Despite this, Hruby's research team demonstrated the disturbing effect of the antimeridian, because their experiment significantly improved the number of students whose distances were not measured through the countermeasure of the projection.

The participants had to arrange three point-pairs according to their true spherical distance. Two of the three point-pairs had to be connected crossing the antimeridian, but only one point-pair was placed so close to the antimeridian that their proper connection in this way would be evident. Since we did not want the other distorting effects of the projection to influence the result, our experiment was carried out using the Baranyi IV projection, which is considered to be favourable for the whole globe and is widespread in the Hungarian cartography (Figure 4). The control group got a map in the Ginzburg projection (Gott, Mugnolo & Colley, 2007), which contains discontinuity only at a single point, optimally depicting the spherical distances. The projection was used in oblique aspect to avoid confusing amounts of distortion at the points examined (Figure 4).

53.7% of the test group gave the correct answer. In the control group, 61.3% of the participants indicated the correct answer. The most common mistake was due to the improper interpretation of the Auckland–Lima distance (see Figure 4): 25.0% of the test group did not connect the points far from the antimeridian crossing the edge of the map but through its centre and seemed thus further as the distance between Dakka and Manaus, which are nearly antipodes. For the control group, this error was less typical, only 12.6%.

In contrast to the study of Hruby, Avelino, and Ayala (2016), there was no significant difference between the test and control groups in any demographic class. It is notable that, in contrast to other age groups, those under the age of 25 performed better using the test map. Although the double image of the antimeridian did disturb some participants, the difference between these projections was much smaller than expected.



Put the distances of the point pairs in ascending order (from shortest to longest) according to their real distance on the Earth.

A) Auckland–Lima; Dakka–Manaus; Midway-Isl.–Honolulu (2)

B) Dakka–Manaus; Auck-land–Lima; Midway-Isl..–Honolulu (1)

C) Auckland–Lima; Midway-Isl.–Honolulu; Dakka–Manaus (4)

D) Midway-Isl.–Honolulu; Auckland–Lima; Dakka–Manaus (6)

E) Dakka–Manaus; Midway-Isl.–Honolulu; Auckland–Lima (3)

F) Midway-Isl.–Honolulu; Dakka–Manaus; Auckland–Lima (5)

Figure 4. Test question of the cut on the antimeridian.

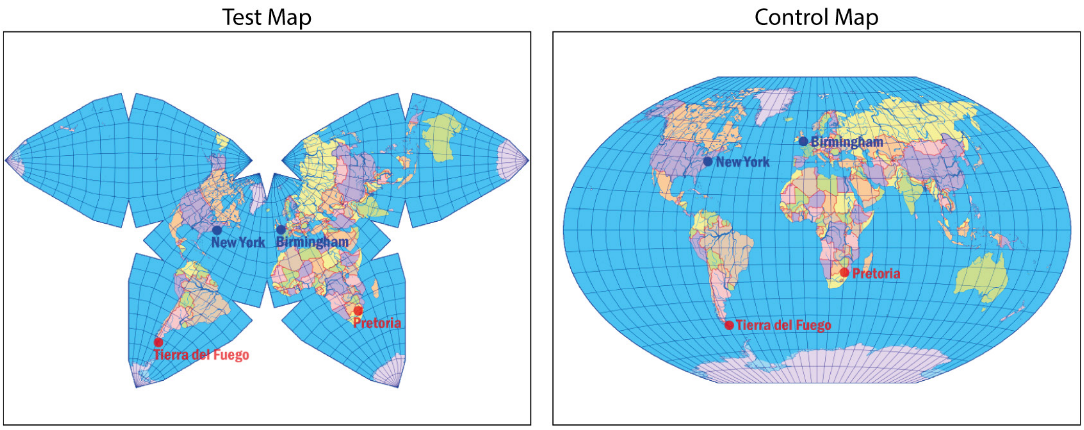
Discontinuities in the Centre of Maps

Although the continuity of maps breaks only along the antimeridian in most projections, there may be cuts in other locations of the map to reduce distortions. Depending on their derivation, these mappings are called interrupted or polyhedral projections. Non-professionals with good marketing capabilities from time to time “discover” the potential of more favourable distortions in polyhedral projections, which the tabloid journalism loves to catch up. Thereafter, it usually receives a negative response from professional cartographers indicating that the map structure falls apart in exchange for the lower distortion of the polyhedral projections, and objects that are close to each other are far apart on the map. The scientific debate is still going on (Böhm, Koch, & Stams, 2017). We wanted to determine whether the cuts of polyhedral projections differ from discontinuities that are usual in the mapping practice.

We selected Waterman's butterfly projection for the map of the test group, the creator of which is also not a cartographer, but the projection complies with the standard rules of map projections (symmetric graticule, its construction can be expressed by explicit formulas), and its distortion is favourable (Figure 5). The participants had to estimate the length of an interrupted section (Pretoria–Tierra del Fuego) taking an uninterrupted section (New York–Birmingham) as the unit. The members of the control group did the same on the only slightly worse but uninterrupted Winkel III projection (Figure 5).

39% of the test group correctly answered that the interrupted length was one and a half times longer. The most common misconception was that the distances are nearly the same, marked by 31.6% of this group. By contrast, 52.3% of the control group correctly estimated the distance, and 27% thought that these distances are the same. Taking the demographic variables into account, the control group performed better in all cases. For those with secondary education, this shows a significant difference according to the t-test, while among men according to the U-test.

Gott, Mugnolo and Colley (2007) find it equally undesirable if two points are located far apart because of a cut, as if the linear scale would cause the same increase in distance. Other authors argue that map users typically overestimate the distances measured on an interrupted map (Hirtle & Jonides, 1985; Hruby, Avelino, & Ayala, 2016). Our results contradict this since underestimation was the most common error on the test map. From our results, it can be concluded that the cuts do not result in overestimation of the distances, as supposed previously, rather in overcompensation of the distortion caused by the discontinuities.



Which statement is true considering the shortest path on the surface of the Earth?

A) The distance between New York and Birmingham is the same as the distance between Tierra del Fuego and Pretoria. (4)

B) The distance between Tierra del Fuego and Pretoria is 1.5 times longer than the distance between New York and Birmingham.

C) The distance between Tierra del Fuego and Pretoria is 2 times longer than the distance between New York and Birmingham. (5)

D) The distance between Tierra del Fuego and Pretoria is 3 times longer than the distance between New York and Birmingham. (2)

E) The distance between Tierra del Fuego and Pretoria is 1.5 times shorter than the distance between New York and Birmingham. (3)

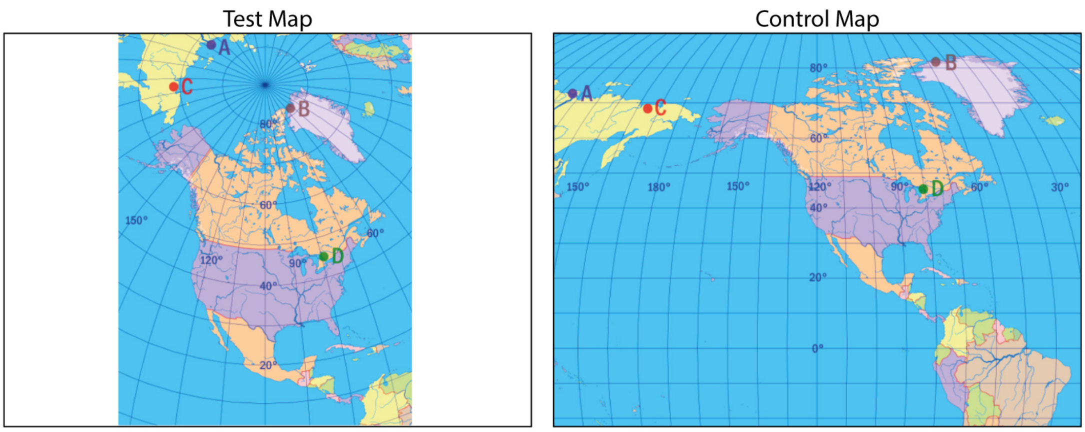
F) The distance between Tierra del Fuego and Pretoria is 3 times shorter than the distance between New York and Birmingham. (1)

Figure 5. Test question of the discontinuities in the centre of maps.

Understanding Curved Graticule Lines

It can be shown that straight parallels are preferred to curved ones among map users (Šavrič et al., 2015), although this survey covered only world maps. The indisputable advantage of straight-line parallels is that they show geographical zones expressively.

In our task, participants arranged four points from north to south. The test group received an oblique Lambert azimuthal projection. An important feature of this projection is that it is possible to depict a point beyond the North Pole. On the map, we added a point beyond the image of the North Pole. The control group arranged the same points in the Kavraysky VII projection (Figure 6). This projection is one of the best pseudo-cylindrical projections used in practice.



Put the points in order from the northernmost one to the southernmost one.

A) A B C D (4)
B) A C B D (2)
C) B A C D (6)
D) B C A D (5)
E) C D A B (1)
F) C B A D (3)

Figure 6. Test question of the understanding of curved graticule lines.

95.6% of the experimental group indicated the correct B-A-C-D answer. Similarly, a high score was achieved in the control group since 92.8% indicated the correct response. Overall, there was no significant difference between the two projections in any demographical group. Our test subjects relied on the graticule lines to interpret geographic relationships.

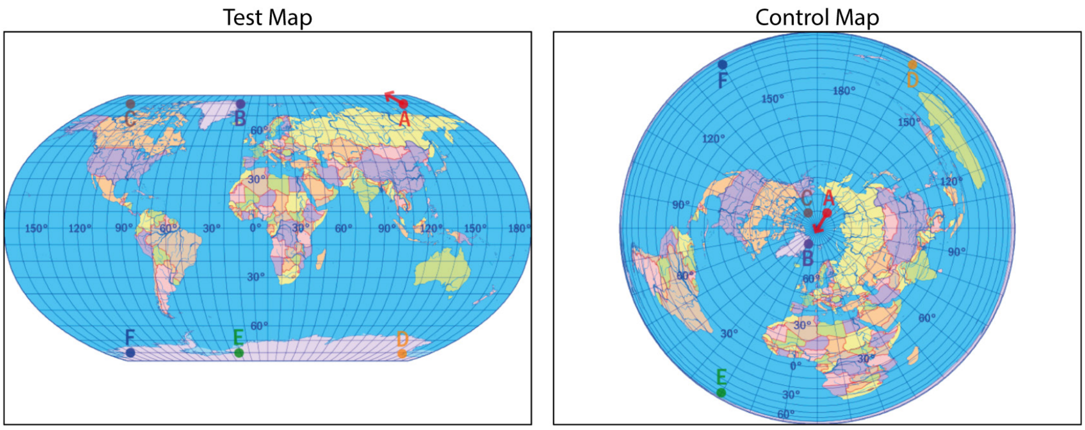
Pole-lines

Cartographia Co. and its successors, which dominated the market of Hungarian school atlases for many years, used maps exclusively with pole-points in educational publications. They typically applied the Baranyi IV projection for world maps, which has favourable distortions and pole-point. Following the secularization of the textbook market in 2016, new school atlases are being produced exclusively by Stiefel Ltd., whose world maps are drawn in Winkel III projection with a pole-line (Fábiánné Merk et al., 2016) leaving off traditions. Therefore, the knowledge of map readers about pole-line should be investigated. Based on an earlier user-study (Šavrič et al., 2015), map users do not consider the pole-line unusual, there is no significant preference for either pole-point or pole-line maps. However, it has to be checked whether the interpretation of these popular projections with pole-lines is correct.

Six points were marked on the Robinson projection, and the test-subjects had to say which one of the six points was touched when departing in the direction of the arrow pointing to the pole-line (Figure 7). Points were also placed in the neighbourhood of the opposite pole-line. The control group worked on the Lambert azimuthal projection (Figure 7), which illustrates better the polar region.

32.4% of the experimental group indicated the correct answer B. The same number of participants (21.3%) marked the C and D responses. In the control group, 76.6% of participants gave the correct answer. According to each demographic variable and both evaluation methods, there was a significant difference between the test and control groups. Without exception, better performance was observed for those who used the control map for this task. At the same time, there was an interesting difference between the genders in reading the test map (with pole-line). 43.1% of men and only 20.3% of women solved the task correctly. The overwhelming majority (75.9%) of participants answering D (who immediately arrived at the South Pole after "leaving the map" at the North Pole) were women. In the control group, there was no such difference between genders. For this task, the probability of the U-test was below 0.005% for most cases.

Our results show that pole-point representation is the ideal solution for maps showing higher latitudes. In view of this, it is worth noting that the projection used in our newer school atlases undermines the interpretation of polar regions.



Which point would you reach, if you followed the red arrow from point A along the meridian, and crossed the edge of the map?

A) Back to A (4)	**B) B** (6)	C) C (5)
D) D (2)	E) E (3)	F) F (1)

Figure 7. Test question of the understanding of pole-lines.

Second Term of Correction

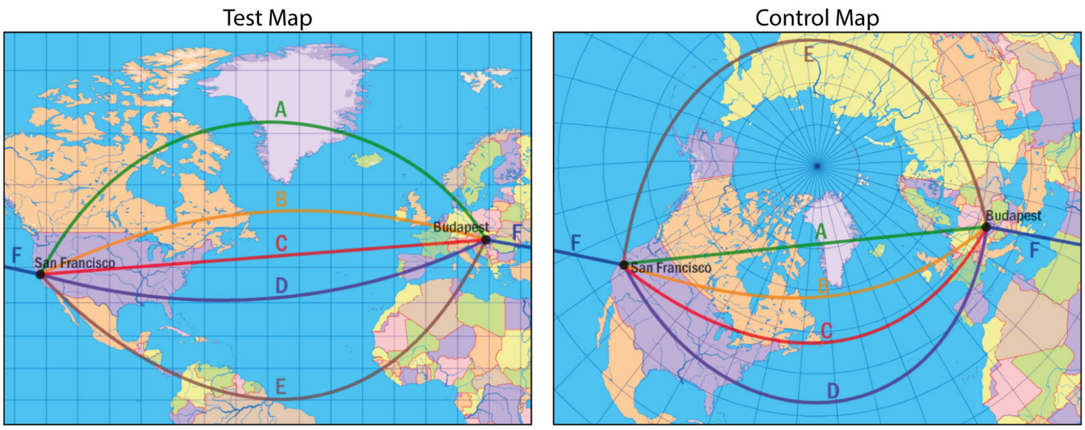
In our final question, we wanted to assess the extent to which the map readers are aware of the curvature of the mapped geodesic lines. Small-scale maps may display large distances, so the second term of correction influences directions measured in the projected plane by orders of magnitude more than usual in the geodesy, here with a value of about 75°.

The mapped image of geodetic lines on world maps may be extremely complicated: they can be simple curves, but geodetic lines crossing the Equator often appear as a twisted S-shape. A study using the thinking aloud method among geography students and teachers (Anderson & Leinhardt, 2002) has shown that knowledge is especially scarce among university researchers. The participants had more knowledge regarding the Northern Hemisphere, as it is more often mentioned in the examples, and because of the heavier flight traffic, they have more personal experience. No control group was included in the study.

Our investigation was carried out in the Northern Hemisphere, which is more affected by preconception; subjects were asked to read the shortest route from San Francisco to Budapest from the map. There were six pre-drawn paths, one of which linked the cities across the edge of the map in a misleading way. The map is made in Miller cylindrical projection, in which there is no meridian convergence at all, and the first term of correction distorts directions to a negligible extent. The map of the control group is not gnomonic projection, which is free of curvature. Its large linear scale may have caused distrust and the first term of correction would also be disturbing for such a big distance. It was, however, appropriate to use an azimuthal projection with its meta-pole in the midpoint of the geodesic line because the analysed section would be a meta-meridian mapped to a straight line. Other distortions were equilibrated using Airy's minimum-distortion azimuthal projection (Figure 8). Due to the properties of the projection, it was not possible for the two groups to draw the path "E" along the same trace, but this answer was the longest route for both groups.

42.6% of the experimental group indicated the correct response. The most common incorrect option was C with 25.7%. 39.6% of the control group gave the correct answer, and the most common incorrect answer (i.e. C) reached 36.9%. Only the U-test indicated significant differences between the results of the test and control group. In the case of age categories, the group of those under 20 were significantly better using the control map. This trend turned over for ages 25-30, and the results of the experimental group became better, approaching the critical value of the U-test. The results for the different levels of education were similar: while among people with primary education the control group achieved a significantly better result, in the case of those with higher education, the test group performed better, also not far from reaching the level of significance. professionals in geography or earth sciences and in men achieved significantly better results using the experimental map.

The control map hindered some groups rather than helped the correct interpretation. Because of the frequent use of conformal world maps, map users are accustomed to the fact that straight lines map to curves. At the same time, less experienced groups could benefit from the less distorted projection. All in all, it can be stated on this task that the more experienced map users were not willing to accept the "correct" map as distortion-free. They even tried to eliminate the usual distortion when it did not even appear on that map.



Which is the shortest route from Budapest to San Francisco by aeroplane?

A) A (6)	B) B (5)	C) C (4)
D) D (4)	E) E (3)	F) F (1)

Figure 8. Test question of the second term of correction.

SUMMARY

Our results strengthen Wakabayashi (2013) in several cases, who said that the interpretation of small-scale maps is based on the geographical knowledge. This also means that the more often a map reader reads maps with specific properties, the stronger the preconception of the "right" maps becomes. Based on this, the importance of choosing the right projection also increases, because it is not only an aesthetic question but also affects the worldview of map readers.

The results show that the applied projections affected more the younger age group (under 20 years), suggesting that they have fewer prejudices on map projections. This means that the role of map editors is particularly important for young people, as it is easier to influence the worldview of this group. At the same time, it should be noted that the small number of people in this group may have influenced our results. The prejudice mentioned previously was most apparent among participants experienced in geography and earth sciences, who could perform well with the usual projections, while sometimes their performance was even lower than their inexperienced peers.

The presence of the pole-line seemed to cause the biggest problem for the participants. On the basis of our results, we only propose maps with pole-lines when the map thematic does not cover high latitudes, and the distortions of the pole-line map are considerably more favourable than the corresponding pole-point map.

In conclusion, our research showed that projections play a significant role in reading small-scale maps. Apart from the aesthetic appearance, it is necessary to take the feature parameters into account as well, as they can improve the map reading ability of the users.

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